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CHANGES IN THE DECLINE STATUS OF HARDWOOD FORESTS IN ONTARIO 1986 to 1987

DECEMBER 1989

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Changes in the decline status of
hardwood forests in Ontario :
1986 to 1987.

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CHANGES IN THE DECLINE STATUS OF HARDWOOD FORESTS IN ONTARIO 1986 to 1987

Report prepared for:
Air Resources Branch

Report prepared by:
Ecological Services for Planning Ltd.
Guelph, Ontario

DECEMBER 1989

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EXECUTIVE SUMMARY

In response to concerns regarding the possible role of atmospheric pollutants in the decline of hardwood forests in Ontario, the Ontario Ministry of the Environment has initiated a series of projects to examine this problem within the Acidic Precipitation in Ontario Study (APIOS) program. One component study established under this program, the Hardwood Decline Survey, was intended to assess the degree and extent of existing damage to selected hardwood forest sites in the Great Lakes-St. Lawrence and Deciduous Forest Regions of Ontario.

The survey was intended as an inventory of the current decline conditions. Identification of the cause of decline and the examination of the relationship with atmospheric pollutants were not objectives of this study. The plots were selected with the intention that they would be accessible for future periodic re-evaluation. The objective of the 1987 survey was to provide both a temporal and a spacial perspective on the changes in the condition of the hardwood resource in Ontario. This report documents the results of the reassessment of the Province-wide Hardwood Decline Survey plots conducted in 1987.

Plot average decline indices for 1987 for sugar maple and for all tree species combined correlated well with patterns of insect defoliation throughout Ontario. In the Algonquin, Parry Sound, and Muskoka areas, many of the plots increased in decline index relative to the 1986 survey. In general, increases in decline index tended to correspond to the severe infestation of forest tent caterpillar and other agents, including the Bruce Spanworm, during the 1986 and 1987 growing seasons. Several plots along the north shore of Lake Huron also increased in decline index. This area was subject to local, severe infestations of the forest tent caterpillar in 1987. Plots in southwestern Ontario (especially in the Niagara and London areas), and in eastern Ontario (especially in the Cornwall area) also increased in decline index. Several of these plots corresponded to mapped sightings of egg masses of gypsy moth. Several plots in eastern and central Ontario showed a decrease in the decline index. This apparent recovery of these stands may be related in part to the collapse of the gypsy moth populations in this area.

Other than the plots corresponding to areas of severe defoliation, average decline indices for 1987 were very similar to the results from the 1986 survey. For the majority (67%) of the non-defoliated plots, the decline indices changed less than one standard deviation.
This suggests that decline index mapping is repeatable from year to year, and supports the validity of the assessment procedures used.

Currently, 3.4% of the trees in the Hardwood Decline plots are dead. Approximately 1.3% mortality has occurred since the 1986 survey. At present, there are no provisions made to account for

mortality and ingrowth within the plots, since each plot consists of a fixed number of trees. To allow for mortality and ingrowth in future surveys, the plots must be changed to a fixed area to encompass a changing number of trees over time, rather than a fixed number of trees.

The strongest correlations of the mean decline indices for 1987 are with insect defoliation levels within the plots. Correlations with the additional tree quality observations are weak. There are no consistent patterns that are discernible with respect to wet sulphate deposition within the study area. The patterns that were discerned with respect to Forest Sectors can mostly be attributed to defoliation patterns, with the following exceptions. There is a general trend for the northern Ontario plots to have a higher decline index than the plots located in southern Ontario. This is probably related to macroclimatic and soil differences. Within southern Ontario, the plots located in the highest pollution loading area (especially the Aylmer, Cambridge, and Niagara Districts) have higher decline indices than plots located in the central and eastern portions of southern Ontario, where climate and soil conditions are similar.

This pattern may reflect differences in stand management, since few large hardwood stands remain in southwestern Ontario. The stands in which the plots are located have been utilized for a variety of purposes, such as tapping for maple syrup production and fuelwood cutting, for a longer period of time compared with more northerly locations. Direct cause and effect relationships between decline index and pollution loading levels were not possible to establish from the results of this survey, although this was not an objective.

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ACIDIC PRECIPITATION IN ONTARIO STUDY. HARDWOOD FOREST DECLINE SURVEY: 1987

1.0 INTRODUCTION

In recent years some of the damage observed in forest ecosystems has been attributed to anthropogenic air pollutants. Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) are emitted from industrial and urban centres of the United States and Canada and deposited hundreds, or even thousands, of kilometers away, according to prevailing winds and seasonal weather patterns (Ministry of the Environment 1980; Environment Canada 1982; Ellenton and Misra 1984). Ozone has also been shown to adversely affect crop productivity in Ontario (Linzon et al 1984), and it is suspected to reduce growth of sensitive forest trees in high deposition zones (Hinrichson 1986; Klein and Perkins 1987).

Vegetation is constantly exposed to a wide range of natural environmental stresses such as drought, adverse temperature, and insect and disease epidemics. Anthropogenic stresses imposed by air pollutants are concurrent with these natural stresses and can act synergistically so that their cumulative effect is much more potent. Therefore, it is usually difficult to identify single causal factors responsible for damage, decline, or productivity losses.

In this report, the term "atmospheric pollutants" will be used to refer to the entire range of common airborne pollutants including

"acid rain". A more appropriate term for acid rain is acidic deposition because it includes all forms of wet precipitation as well as dry deposition of gaseous and particulate materials.

At last count, there were nearly 200 theories on the causes of forest decline. However, most are variations or regional examples of one of six major hypotheses. These hypotheses are: (1) general stress, (2) soil acidification and toxicity to roots, (3) ozone injury, (4) foliar nutrient leaching, (5) excessive fertilization and (6) growth altering organic compounds. The following brief descriptions of the above are adapted from Hinrichson (1986).

The general stress hypothesis suggests that the forests have been exposed to several decades of sub-acute air pollution mixtures. This decreases the photosynthetic efficiency of trees, reduces vigor and disturbs the energy budget. The production of phenols and terpenes within the trees are reduced, therefore increasing susceptibility to insects, disease and other natural stress factors. The trees die of natural causes, thereby obscuring the anthropogenic connection.

The soil acidification and toxicity to roots hypothesis suggests that natural acidification of forest soils is accelerated by acidic deposition. Nutrients essential to tree growth are leached from the soil at a rate exceeding replacement thereby inducing nutrient deficiencies. At the same time, potentially toxic elements like aluminium, increase in availability as soil pH decreases, causing

root mortality. Reductions in fine root biomass inhibit the trees' ability to supply moisture and nutrients from the reduced supply, resulting in crown dieback which mimics moisture and/or nutrient stress.

The ozone hypothesis suggest that photo-oxidants directly incite tree decline by injuring the foliage through chronic ozone exposure. A reduction in photosynthetic capacity leads to reduced carbon assimilation and eventually to reduced fine root growth. Ozone injury causes the leaf cell membranes to be more permeable and therefore the cell constituents are more accessible to the leaching by the strong acids in acidic precipitation.

The foliar nutrient leaching hypothesis expands on the foliar damage caused by chronic exposure to air pollutants and suggests that magnesium deficiency symptoms develop in the crown when these elements are lacking in the soil. Trials in Europe have been successful in reviving certain symptomatic trees by soil fertilization with the deficient element as diagnosed by foliar analysis.

Acidic deposition contains nitrogen as well as sulphur. The excessive fertilization hypothesis suggests that the forest may be over-fertilized with nitrogen and that trees may absorb nitrogen from precipitation directly through the foliage. Over-fertilization with nitrogen encourages rapid growth, creating a demand for additional

nutrients which may not be available in the required amounts from the soil. Nitrogen over-fertilization also may result in late season growth resulting in reduced cold hardiness, and making the tree more susceptible to frost damage or winter injury.

The growth-altering organic compounds hypothesis is somewhat speculative. This theory recognizes that in addition to the "normal" air pollution components, there are numerous organic compounds in the atmosphere. Some of these compounds are, or may mimic, natural plant hormones such as ethylene, thereby possibly adversely altering tree growth.

Extensive dieback and mortality of several tree species have been reported since the 1970's in Europe. Until recently, concern centered on coniferous species, particularly fir and spruce; however, several hardwood species are now similarly affected. In North America, decline episodes of both hardwoods and softwoods have been recorded at intervals throughout this century. Decline of red spruce and balsam fir has been severe in certain locations in the northeastern United States since the early 1980's. Sugar maple decline has been severe and widespread in the eastern townships of Quebec, and has increased since 1981 (Desserault 1986).

Concern has recently been expressed regarding the possible role of atmospheric pollutants in the decline of hardwood forests in Ontario. In response, the Ontario Ministry of the Environment has initiated

a series of projects to examine this problem within the Acidic Precipitation in Ontario Study (APIOS) program. One component study established under this program, the Hardwood Decline Survey, was intended to assess the degree and extent of existing damage to selected hardwood forest sites in the Great Lakes-St. Lawrence and Deciduous Forest Regions of Ontario (Figure 1).

Establishment of the plots and the results of the initial 1986 survey were reported in McIlveen et al (1988). This report documents the results of the reassessment of the Province-wide Hardwood Decline Survey plots conducted in 1987.

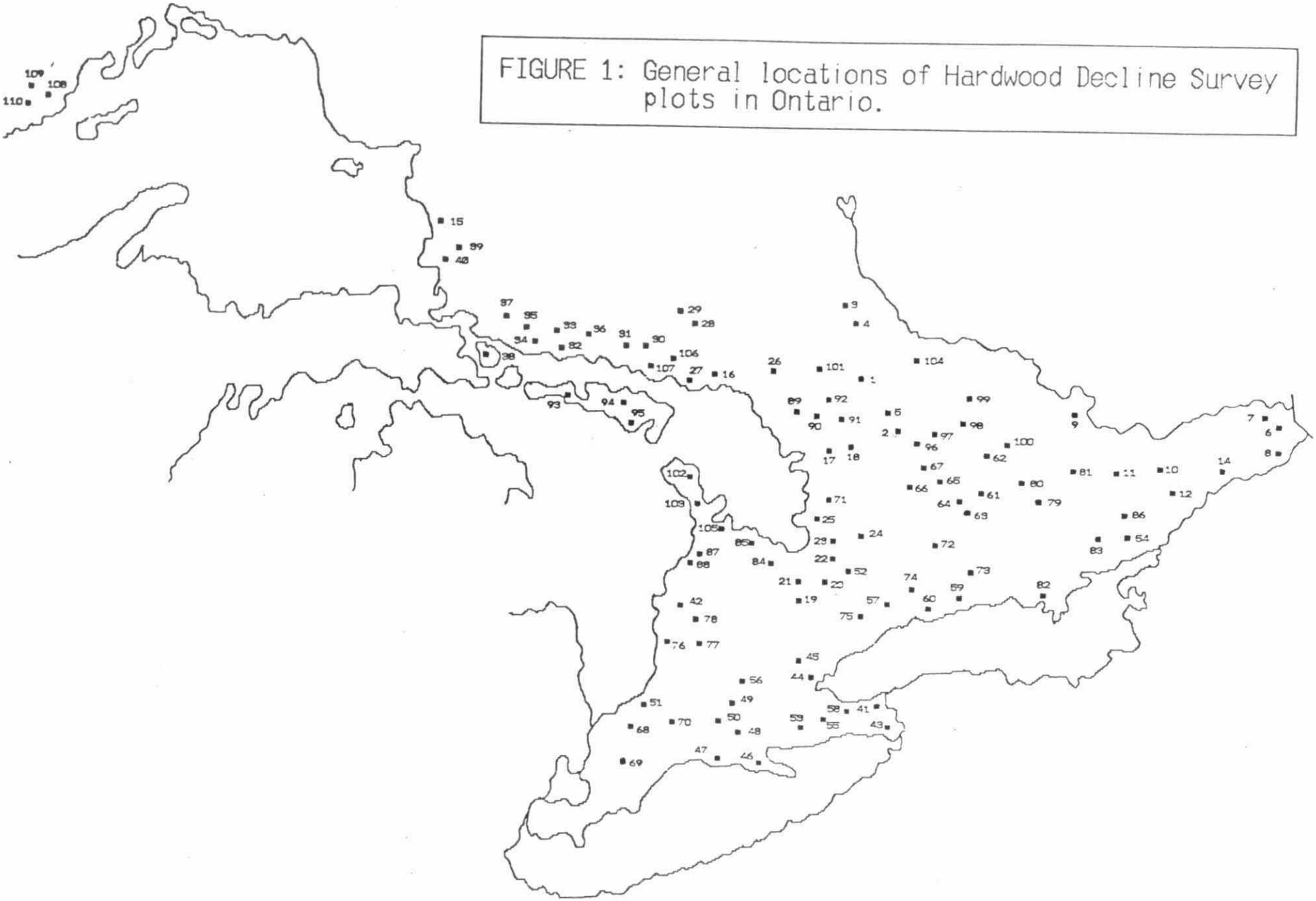


FIGURE 1: General locations of Hardwood Decline Survey plots in Ontario.

2.0 STUDY OBJECTIVES

The objectives of the original study were:

(1) to establish a network of permanent observation plots in which baseline data can be obtained regarding the condition of hardwood forest tree species (sugar maple was the primary target species).

(2) to develop a rating system to assess the condition of hardwood trees with respect to the symptomatology experienced in Ontario.

(3) to evaluate the assessment data and determine if regional differences are apparent in forest tree condition.

The survey was intended as an inventory of the current decline conditions. Identification of the cause of decline and the examination of the relationship with atmospheric pollutants were not objectives of this study although certain patterns may become apparent in analysis of the data. The plots were selected with the intention that they would be accessible for future periodic re-evaluation. The objective of the 1987 survey was to provide both a temporal and a spacial perspective on the changes in the condition of the hardwood resource in Ontario.

3.0 TECHNICAL PROGRAM

The initiation of the survey in 1985/86, including the selection and establishment of the survey plots, and field survey methods are described by McIlveen et al (1988). Quality control procedures are described by the Quality Assurance Manual for the Hardwood Decline Survey (Ecological Services 1987). The following discussion summarizes the field procedures used during the reassessment of the Hardwood Decline Study Plots during the summer of 1987.

3.1 Plot Maintenance

Maintenance was conducted on all the study plots during the 1987 field season to facilitate relocation and assessment, and to provide buffer zones to prevent disturbance to the plots. The tree identification tags were replaced with sequentially numbered tags placed at breast height on each tree, oriented horizontally, and fixed in place with two galvanized steel nails left protruding about 5 cm to allow for future tree growth.

Three steel T-Bars were placed at each plot. The first was placed at the point of access to the stand from the road. Two more T-Bars were placed 30 metres north and south of the plot boundaries. Plastic 15cm x 20cm signs identifying the plot as an MOE study were wired to these two T-Bars, and were also placed on the 4x4 wooden post located at the plot center. A 10cm x 10cm white plastic marker labelled with the plot number was wired to the T-Bar located at the

road access point. A thirty metre buffer zone was painted with blue tree marking paint, facing outwards, around each plot to identify its location, and to prevent cutting or other disturbance in the immediate vicinity. Variation to some of these plot or tree marking procedures were required if they conflicted with the wishes of the land owner or manager.

The site location information and plot maps were also upgraded. For each plot, exact distances were measured from the nearest population center to major road intersections, to easily identifiable landmarks, and to the T-Bar at the main access point to the plot. From the T-Bar, exact distances and azimuths to the plot center were recorded. Some plots are accessed by trails or temporary bush roads. In these cases, two T-Bars were usually employed to mark both the entrance to the trail, and the access point into the stand to the plot location from the trail. Maps showing the locations of the individual trees in each plot are included in Appendix 1.

3.2 Reassessment Survey

Plots were assessed using standard techniques developed by the Ministry of the Environment (Appendices 2 and 3). An example of the field tally sheets used for the 1987 assessment of the Hardwood Decline Survey plots is included in Appendix 4. The observations were identical to those used in 1986 with the following exceptions which were introduced in 1987.

- height to lowest branch (i.e. the base of the living crown)
- crown width (measured as crown radius to the north and the south of the main stem)
- percent dead branches, split into large branches and twig components
- percent early fall colouration
- percent necrotic leaves
- percent insect defoliation

Dead branches resulting from natural self pruning effects were not considered in the assessment of percent dead branches for each tree.

Since the assessment of some decline attributes, especially chlorosis, is influenced by individual perception and light conditions, quality control checking was conducted regularly to ensure that the assessment results were consistent and comparable between plots and between field crews. At the start of the field program, a training session was held for all field crews. Each crew was provided with visual aids to help in the assessment of decline attributes, including colour scales and percent crown area charts.

Regular quality control checking was conducted by professional staff to verify the accuracy and precision of the field crews. One person in each crew was responsible for completing the actual assessments, in consultation with the other crew member. It was found that this consultation led to more consistent assessment results, as it tended to minimize bias on the part of each individual. Two of the tree

assessors had participated in the original assessments completed in 1986.

The reassessments were initiated in northern Ontario in late July 1987, and proceeded south so that the trees in each plot would be in a similar stage of development at the time of assessment. The survey was completed in mid-September 1987, with the assessment of the southernmost plots in Niagara District.

4.0 ANALYTICAL METHODS

4.1 Data Handling

All plot data recorded in the field were entered into an IBM-PC compatible microcomputer for compilation and statistical analysis, using Ashton-Tate's dBase III Plus database manager as the primary data entry tool. For each tree, a 'decline index' value was calculated, based on the percentage of dead branches in the tree crown, the percentage of slight and/or strong chlorosis, and the percentage of undersized leaves. The decline index formula is as follows:

$$DI = \% DB + (A*\%UL) + (A*\%ST) + (A*SL/2)$$

where: DI = decline index
% DB = (percent large dead branches + percent dead twigs)/2
% UL = percent undersized leaves
% ST = percent strong chlorosis
% SL = percent slight chlorosis
A = (100 - % DB)/400

The decline index is a scaled estimate of tree decline, with values ranging from 0 (no decline, symptom free) to 100 (a dead tree). The greatest weight in the formula is given to the percentage of dead branches. Strong chlorosis and undersized leaves have a weighting that is proportional to the percentage of live branches in the tree, and these categories are given less weight than the percentage of dead branches. Slight chlorosis is given 50% of the weighting of strong chlorosis.

Individual plot files were subsequently merged into one large file

in dBase III and checked against the tally sheets to verify the data. Once editing was completed, this large dBase III file was exported to a binary file for subsequent detailed statistical analyses using the statistical package SYSTAT (Wilkinson 1988).

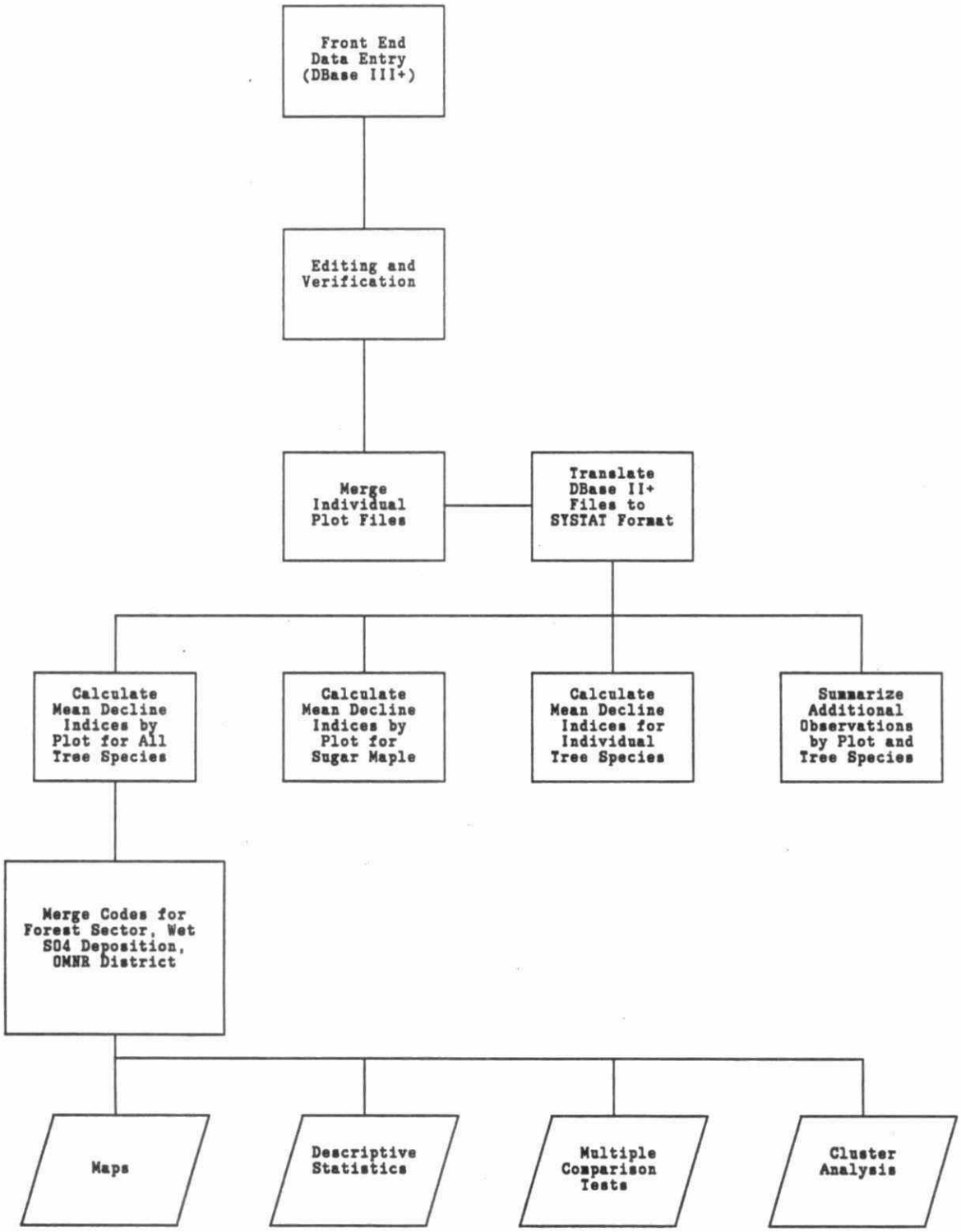
4.2 Data Analyses

An overview of the data analysis procedures used is illustrated in Figure 2. Average plot decline indices were calculated for sugar maple only, and for all the tree species combined. Average decline indices were also calculated for individual tree species for all the plots. The additional tree quality observations were totalled for each plot, for sugar maple only, and for all tree species combined. New data files containing mean values for decline attributes and totals of the additional observations for each plot by tree species were created using these methods.

OMNR Administrative Districts, Forests Sectors, and wet sulphate deposition zones were coded into each of the summary files for each plot to aid in determining regional decline patterns. These files were then used to produce maps to illustrate regional patterns between the plots. Statistical analyses were subsequently performed to test regional differences between Forest Sectors and wet sulphate deposition zones. The plot summary files were also used to examine the relationships between the decline index, the sum of additional observations, and average percent defoliation between plots. The decline indices from the 1986 survey were compared with those from

FIGURE 2

OVERVIEW OF DATA HANDLING AND ANALYSES, HARDWOOD DECLINE SURVEY



the 1987 survey for sugar maple and for all tree species combined.

New files containing records for all of the dead trees within all plots from both the 1986 and 1987 assessment survey results were created. These files were used to calculate a number of dead trees for each plot and tree species, and to estimate mortality occurring from 1986 to 1987.

In addition to examining regional patterns of decline by imposing groupings on the plots (for example, by Forest Sector or sulphate loading zones), plot groupings were formed using the decline attribute data from each plot. The groups thus formed were mapped and examined statistically to see if regional patterns emerged from an examination of differences and similarities between the plots themselves. Hence, two methods were used to examine regional patterns. The first method tested for statistical relationships among the plots according to imposed administrative or environmental boundaries. The second method formed independent groupings of the plots according to the decline attribute data itself, and then examined to see if these groupings correlated with geographic or environmental boundaries.

5.0 RESULTS AND DISCUSSION

5.1 Spacial Distribution of Decline Indices in Ontario, 1986-1987

For mapping purposes, five ranges of decline index were developed (Table 1). The mean decline indices for sugar maple within each of the hardwood decline plots for 1986 are mapped in Figure 3. Mean decline indices for sugar maple in each plot for 1987 are illustrated in Figure 4. The plot mean decline indices for all tree species combined in 1987 are mapped in Figure 5.

The distribution patterns of sugar maple decline indices for the years 1986 and 1987 are quite similar. However, some regional differences are apparent. Decline indices for sugar maple in the Algonquin, Muskoka, and Parry Sound areas have increased (i.e. tree condition has deteriorated) in 1987. In eastern Ontario, including the Cornwall, Brockville, and Napanee Districts, sugar maple decline indices in 1987 are somewhat lower (tree condition has improved) than in 1986, although local variations occur.

On average, the decline indices for sugar maple for the year 1987 are slightly higher than in 1986. The mean sugar maple decline index for all plots was 12.4 for 1986 and 13.6 for 1987, a difference of 1.2. Analysis of variance did not show a significant difference between the distribution of decline indices for the two years, but a paired samples t-test indicated that the mean difference in decline

TABLE 1: Classes used for mapping mean decline indices for the Hardwood Decline study plots.

RANGES OF MEAN DECLINE INDEX	RELATIVE DECLINE RATING	% OF PLOTS IN EACH DECLINE INDEX CLASS SUGAR MAPLE 1986	SUGAR MAPLE 1987	ALL TREE SPECIES 1987
0 to less than 10	very low	25	30	16
10 to less than 15	low	46	28	34
15 to less than 20	moderate	26	25	22
20 to less than 25	high	2	10	17
Greater than 25	severe	1	7	11

FIGURE 3: Mean sugar maple decline indices for the 110 Hardwood Decline Survey plots in Ontario, 1986

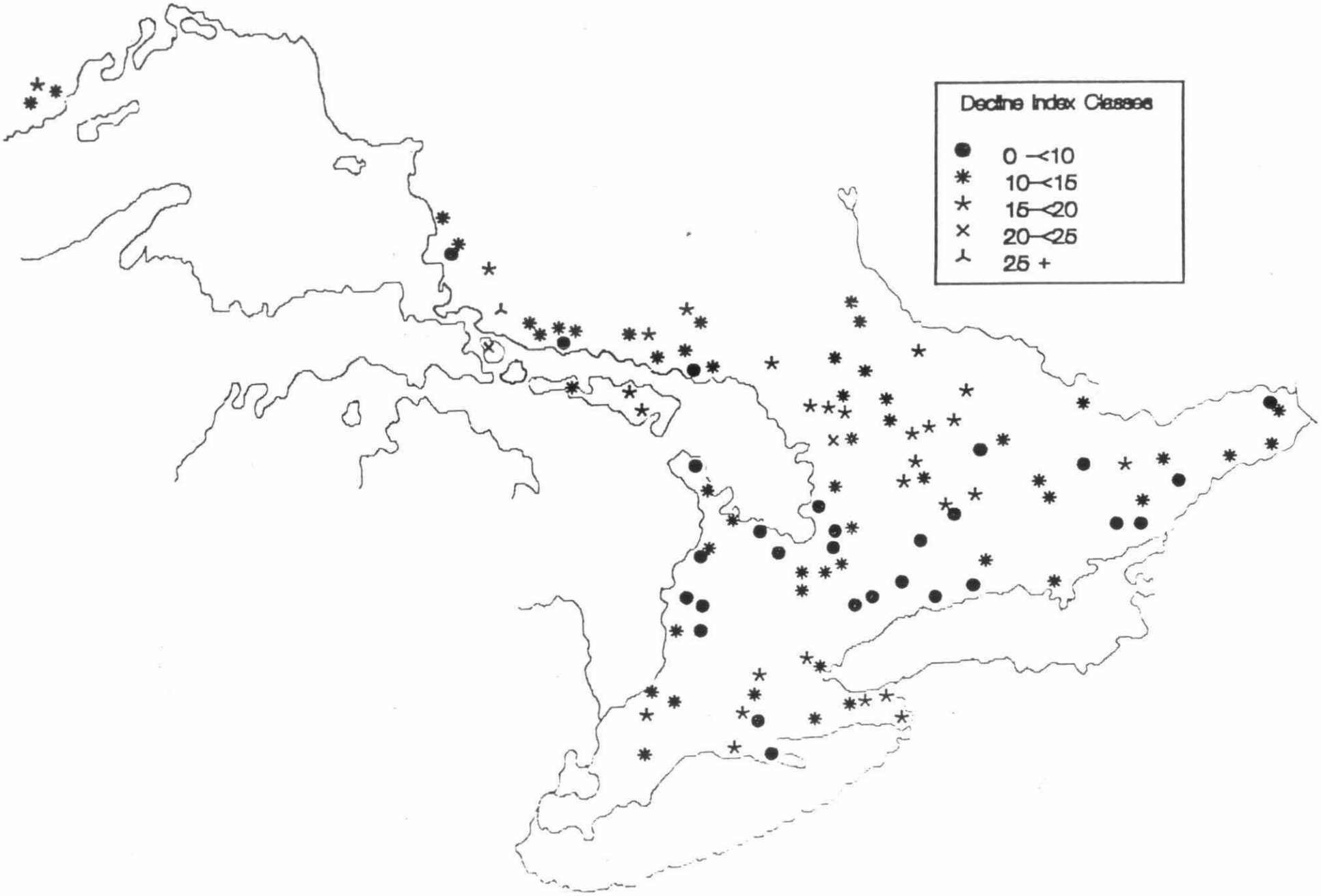


FIGURE 4: Mean sugar maple decline indices for the 110 Hardwood Decline Survey plots in Ontario, 1987.

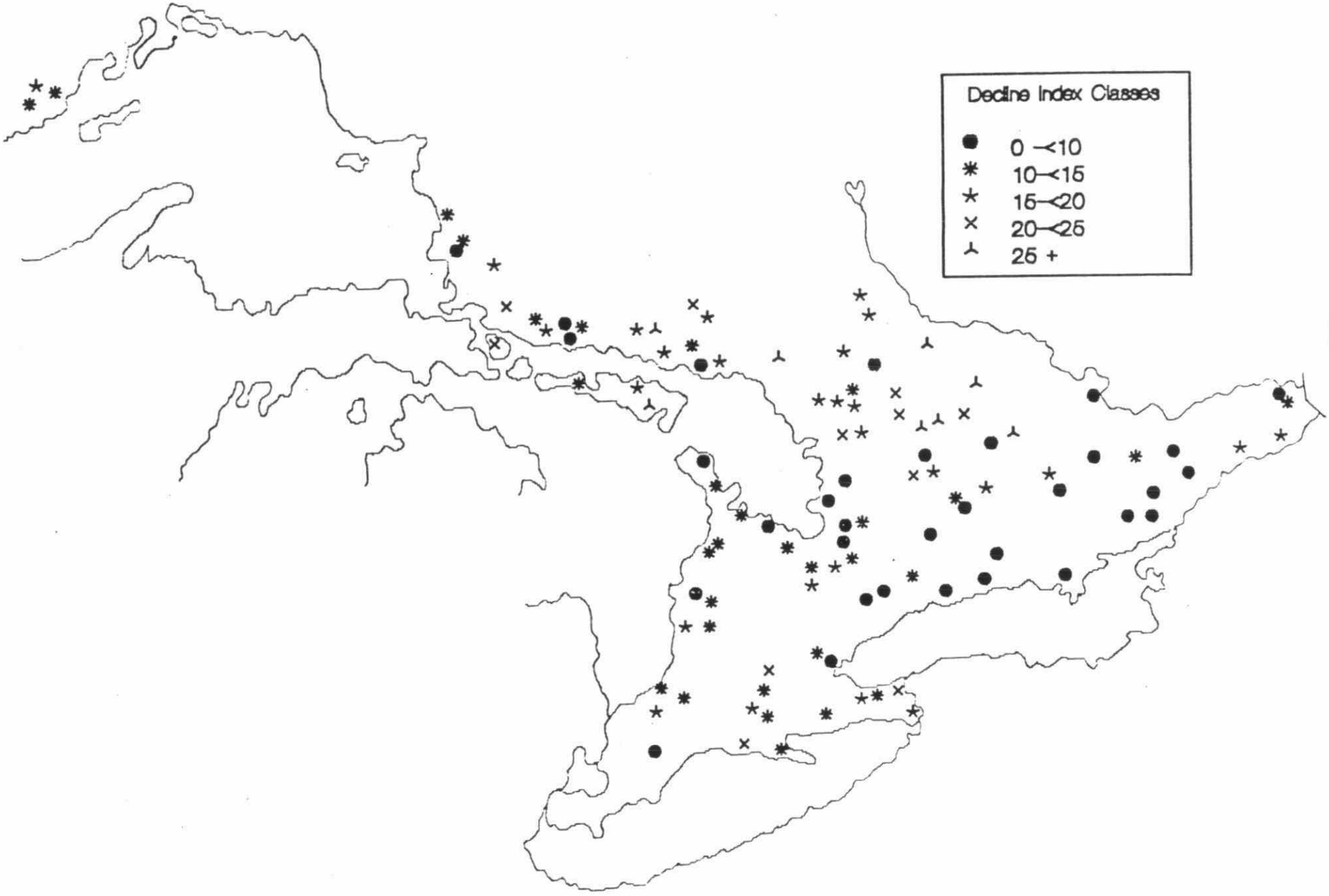
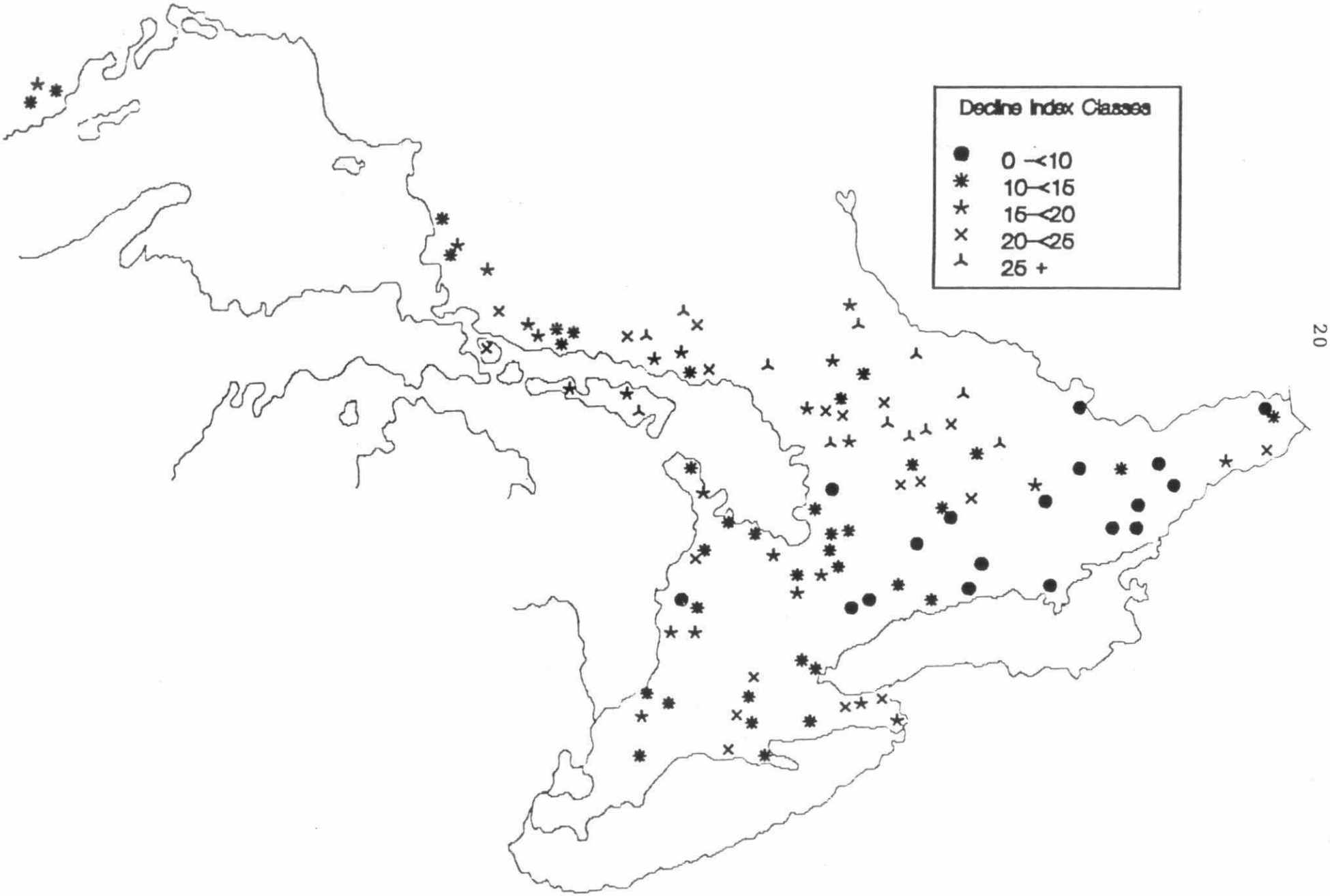


FIGURE 5: Mean plot decline indices (all tree species) for the 110 Hardwood Decline Survey plots in Ontario, 1987.



index between 1986 and 1987 was statistically significant (p=0.026). The same trend is true for decline indices for all tree species combined. The distribution pattern of decline indices in Ontario for all tree species for the year 1987 (Figure 5) is similar to that of the decline indices for sugar maple only, because sugar maple is so dominant (Figure 4), except that the average decline index is slightly higher when all tree species are combined.

The hardwood forest of Ontario is extensive and diverse. Although the 110 plots were established with an attempt to be representative, it is arguable that such a relatively small sample size can accurately reflect the condition of the provinces' hardwood resource as a whole. The most valuable aspect of the survey is the change that occurs at each site from year to year. Since the same trees are assessed with the same methodology, a reassessment of the plots is no longer a survey with an unknown sampling error but rather a measurement exercise where temporal shifts can be quantified.

The standard deviation of the change in the mean plot decline index from 1986 to 1987 was 5.4. Therefore, unless the mean decline index at a plot had changed by more than 5.4 (± 1 standard deviation) the condition of the trees in that plot would be considered unchanged. The results of the 1987 reassessment revealed that the tree condition had not changed relative to 1986 at 74 plots (68%). Tree condition improved (i.e. mean decline index decreased by more than 1 standard deviation) at 11 plots (10%). In contrast, 25 plots (23%) recorded

a deterioration in tree condition. The change in mean decline index from 1986 to 1987 is illustrated in Figure 6.

Although improving/deteriorating plots occurred throughout the survey area, there were apparent regional trends. The greatest number of deteriorating plots were encountered in the Algonquin, Muskoka and North Channel areas. A few occurred in the southwest, but they were quite scattered. By comparison, plots which had improved in condition were less concentrated, but tended to occur mainly in south central and southeastern areas of the province.

Insect defoliation of sugar maple trees was recorded in 1987 in the hardwood decline plots (see Figure 7). Five classes of insect defoliation are mapped: less than 5% (defoliation not significant), 5 to 20% (slight defoliation), 20 to 35% (moderate defoliation), 35 to 50% (severe defoliation), and greater than 50% (very severe defoliation).

Severe and very severe defoliation of sugar maple in the hardwood decline plots occurred in the Muskoka, Algonquin, North Bay, and Parry Sound areas. Severe although more localized defoliation also occurred along the north shore of Lake Huron from near Sudbury to the Sault Ste. Marie area. Localized moderate to severe defoliation also occurred in southwestern Ontario, particularly in the London and

FIGURE 6: Changes in sugar maple decline indices from 1986 to 1987 for the Hardwood Decline Survey plots in Ontario.

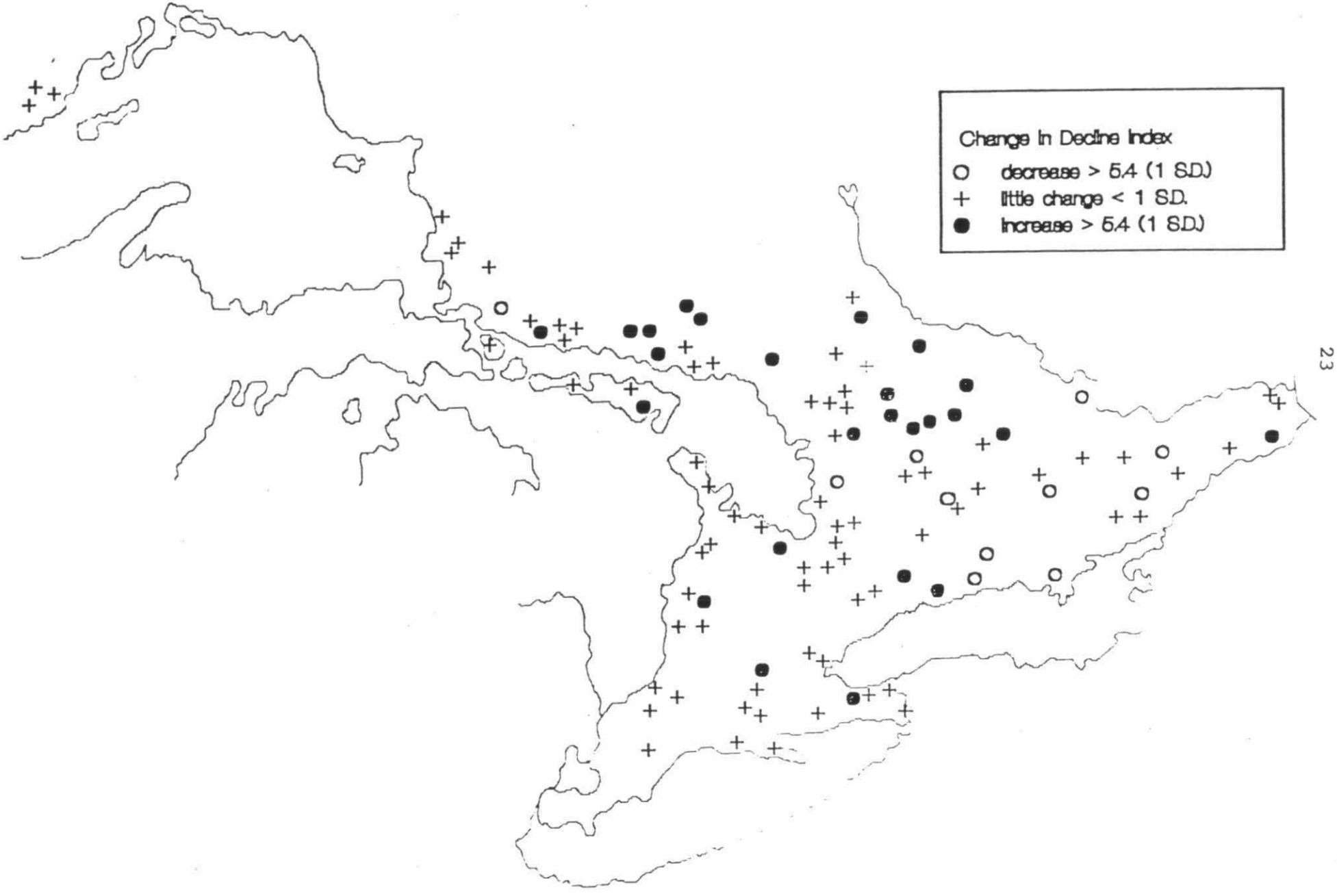
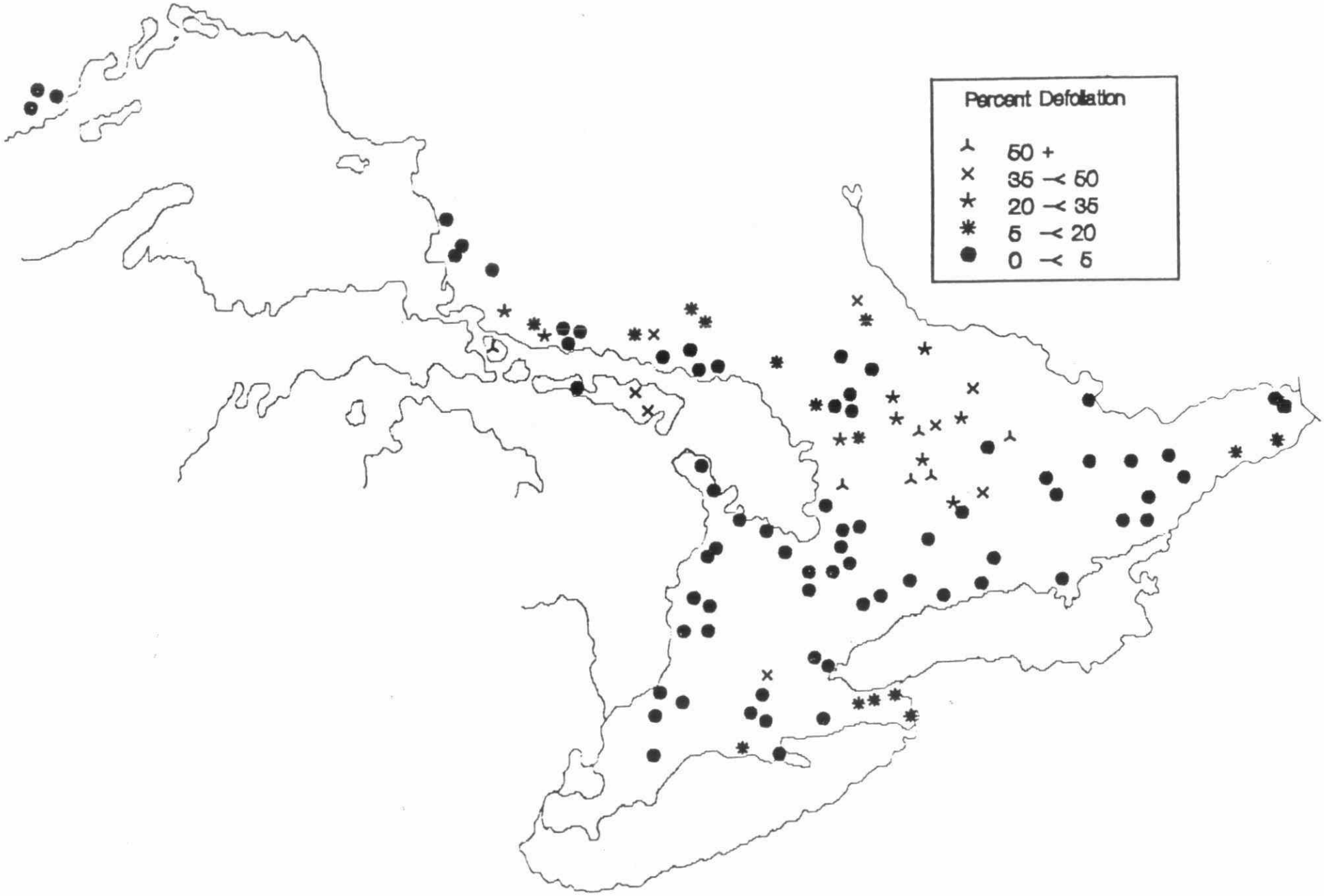


FIGURE 7: Mean percent defoliation for sugar maple for the 110 Hardwood Decline Survey plots in Ontario, 1987.



Niagara areas, and for two plots in the Cornwall district in eastern Ontario. The results of the Forest Insect and Disease Survey carried out annually by the Canadian Forestry Service confirms substantial defoliation of the hardwood forest by both Bruce spanworm and forest tent caterpillar in the north central and northwestern parts of the province (Biggs et al 1987; Sajan and Smith 1988). Localized defoliation by gypsy moth occurred in the southeast and possibly in the southwest (Brodersen and Biggs 1988).

A comparison of Figure 6 and Figure 7 reveals that plots with increasing decline indices correspond very closely to the plots which were moderately to very severely defoliated during the 1987 season. A close examination of the area of heaviest defoliation in the Muskoka and Algonquin areas reveals that the few plots that remained unharmed by the forest tent caterpillar infestation show little change in the decline index, whereas the decline index for plots that were heavily defoliated has increased significantly.

This observation is verified by correlating the change in decline index from 1986 to 1987 with the average percent defoliation for both sugar maple trees and all tree species combined (Table 2). Changes in the decline indices are significantly correlated with mean insect defoliation in both cases ($p<0.001$).

In parts of central and eastern Ontario, the decline indices have decreased for a number of plots. For the past several years, a

TABLE 2: Correlation between percent insect defoliation of sugar maple and all tree species, and the change in decline index from 1986 to 1987.

CHANGE IN DECLINE VERSUS:	PEARSON R-VALUE	PROBABILITY
DEFOLIATION (SUGAR MAPLE)	0.414	<0.001
DEFOLIATION (ALL SPECIES)	0.430	<0.001

severe gypsy moth infestation has plagued local areas of eastern and central Ontario. The population of gypsy moth in this part of Ontario have been declining and largely collapsed in 1987. It is possible that the improvement in the decline index ratings for these plots is related to recovery of the trees from previous gypsy moth defoliation.

5.2 Decline Conditions for each Tree Species

Sugar maple comprised 76% of the total number of trees surveyed. In 1987, sugar maple had a mean decline index of 13.6. This decline index is low relative to most of the other hardwood species assessed during the survey, although variation between trees within the survey is high (the coefficient of variation is 123% for sugar maple). Table 3 summarizes basic statistics for the decline indices for each tree species, including the number of trees surveyed, the mean decline index, standard error, coefficient of variation, as well as the mean number of additional quality defects noted for each tree species. Many hardwood species are not well represented in the assessment, and the mean decline indices for species with a low total number of trees must be interpreted cautiously. In 1987, those species which comprise more than 1% of the survey population are: black cherry, white birch, red maple, yellow birch, ironwood, basswood, white ash, northern red oak, sugar maple, and beech. This list is ordered in decreasing mean decline index (from worst to best condition). Decline indices are not summarized for the coniferous tree species since the current decline classification applies only to hardwoods.

Table 4 lists mean values of individual decline attributes for each tree species. Percent dead large branches, percent dead twigs, strong chlorosis, slight chlorosis, and percent small leaves are used

TABLE 3: Descriptive survey statistics for each tree species: 1987.

HARDWOOD SPECIES

TREE SPECIES	TOTAL NO. TREES	PERCENT OF TOTAL TREES	MEAN DECLINE INDEX	DECLINE INDEX STD. ERROR	DECLINE INDEX COEFF. VARIATION	MEAN NO. DEFECTS
White elm	8	0.07	65	11	49%	2.0
Rock elm	2	0.02	52	10	28%	3.0
White oak	4	0.04	51	16	64%	1.3
Striped maple	3	0.03	45	28	107%	2.3
Weeping willow	4	0.04	32	7	46%	0.5
Bur oak	2	0.02	31	22	101%	1.5
Black cherry	171	1.55	30	2	88%	1.6
Balsam poplar	9	0.08	29	5	54%	2.3
White birch	112	1.02	26	3	100%	1.9
Trembling aspen	97	0.88	25	2	89%	1.7
Red maple	313	2.85	24	1	94%	2.1
Yellow Birch	175	1.59	24	2	110%	2.2
Largetooth aspen	4	0.04	23	8	69%	2.3
Ironwood	295	2.68	22	2	138%	1.7
Black ash	28	0.25	21	4	101%	2.0
Basswood	320	2.91	21	1	97%	1.8
White ash	429	3.90	18	1	114%	1.3
Northern red oak	156	1.42	17	1	95%	1.6
Butternut	3	0.03	17	12	121%	2.7
Tulip tree	1	0.01	17	n/a	n/a	1.0
Bitternut hickory	81	0.74	15	3	154%	1.0
Pin cherry	6	0.05	15	8	137%	0.7
Sugar maple	8309	75.54	14	0	123%	2.1
Beech	307	2.79	13	1	117%	2.0
Norway maple	2	0.02	13	3	29%	3.0
Hickory	5	0.05	3	2	149%	1.0
Average/total:	10846	98.60	15	6	95%	1.8

TREE SPECIES	TOTAL NO. TREES	PERCENT OF TOTAL TREES	MEAN NO. DEFECTS
Hemlock	83	0.75	0.8
White pine	20	0.18	0.8
Eastern white cedar	15	0.14	0.7
Balsam fir	28	0.25	0.4
White spruce	8	0.07	0.4
Total:	154	1.40	0.6

TABLE 4: Summary of the 1987 decline index, decline attributes and percent insect defoliation averages for each tree species, on a per tree basis.

HARDWOOD SPECIES	NO. TREES	DECLINE INDEX	LARGE BRANCHES	% DEAD TWIGS	STRONG CHLOROSIS	SLIGHT CHLOROSIS	FALL COLOUR	EARLY SMALL LEAVES	% NECROSIS	% DEFOLIATION
White elm	8	65	77	46	19	3	4	1.9	4	11
Rock elm	2	52	48	50	25	5	0	0.0	5	0
White oak	4	51	58	41	8	8	3	0.0	5	4
Striped maple	3	45	45	45	0	0	12	0.0	27	0
Weeping willow	4	32	36	16	21	8	15	0.0	18	5
Bur oak	2	31	43	8	30	15	3	0.0	10	18
Black cherry	171	30	35	22	5	9	6	0.9	1	6
Balsam poplar	9	29	31	27	0	0	0	0.0	70	70
White birch	112	26	29	20	7	7	6	1.7	1	11
Trembling aspen	97	25	28	19	4	6	3	0.5	1	5
Red maple	313	24	27	18	6	6	14	0.5	1	11
Yellow Birch	175	24	26	19	4	4	7	1.1	2	9
Largetooth aspen	4	23	19	26	0	0	0	0.0	0	0
Ironwood	295	22	21	20	3	3	5	0.1	2	4
Black ash	28	21	25	14	6	7	2	2.3	1	13
Basswood	320	21	21	17	6	7	3	0.5	1	9
White ash	429	18	18	14	4	9	17	0.4	0	5
Northern red oak	156	17	19	14	2	5	2	0.5	1	12
Butternut	3	17	17	17	0	0	0	0.0	2	0
Tulip tree	1	17	25	5	0	15	10	0.0	0	0
Bitternut hickory	81	15	16	12	1	8	25	1.0	1	1
Pin cherry	6	15	13	10	8	8	0	0.0	0	0
Sugar maple	8308	14	14	10	4	5	7	0.8	1	10
Beech	307	13	14	11	3	4	7	0.8	2	7
Norway maple	2	13	10	10	10	3	5	0.0	0	0
Hickory	5	3	3	3	0	0	0	0.0	3	2
Total Trees:	10846	(98.6%)								
Averages, all species:		25	27	20	7	6	6	0.5	6	8

CONIFER SPECIES	NO. TREES	DECLINE INDEX	% DEAD LARGE BRANCHES	% DEAD TWIGS	STRONG CHLOROSIS	SLIGHT CHLOROSIS	EARLY FALL COLOUR	SMALL LEAVES	% NECROSIS	% DEFOLIATION
Hemlock	8	(Decline attributes are not applicable to conifers)								1
White pine	28									3
Eastern white cedar	20									6
Balsam fir	15									2
White spruce	83									8
Total Trees:	154	(1.4%)								
Average defoliation:										4

directly in the calculation of the decline index. Mean percent early fall colour, percent necrosis, and percent insect defoliation are also summarized. To aid comparison, the tree species are listed in the same order as in Table 3 (in order of decreasing decline index).

Table 5 summarizes tree mortality in the plots for each tree species. A total of 341 trees, or 3.1% of the total number of trees in the plots, were dead in 1987. Tree mortality from 1986 to 1987 was 1.3%. This is considered natural for the forest ecosystems represented in the survey. An examination of notes on the tally sheets showed that most of the mortality that occurred from 1986 to 1987 was the result of windthrow, probably due to ice and windstorm damage.

There are no provisions within the current procedures of the hardwood decline survey to deal with either mortality or ingrowth within each plot. Since each plot consists of a fixed number of trees, decline indices in the future can be expected to gradually increase as natural mortality and aging of the trees in each plot occurs. To assess changes in decline index over time, provision will be made for ingrowth and mortality. This will be accomplished by converting to fixed area plots and tallying trees as they grow into the minimum 10 cm size and dropping dead trees from the tally as they are windthrown.

TABLE 5: Summary of mortality within the hardwood decline study plots from 1986 to 1987, for each tree species.

HARDWOOD SPECIES	Total No. Trees	Number of Dead Trees 1986	Number of Dead Trees 1987	Mortality 1987	1987 Mortality As Percent of Total Trees
White elm	8	4	4		
Rock elm	2				
White oak	4				
Striped maple	3		1	1	33.3
Weeping willow	4				
Bur oak	2				
Black cherry	171	13	17	4	2.3
Balsam poplar	9				
White birch	112	7	7		
Trembling aspen	97	4	4		
Red maple	313	9	15	6	1.9
Yellow Birch	175	9	12	3	1.7
Largetooth aspen	4				
Ironwood	295	21	35	14	4.7
Black ash	28		1	1	3.6
Basswood	320	5	11	6	1.9
White ash	429	16	22	6	1.4
Northern red oak	156	3	4	1	0.6
Butternut	3				
Tulip tree	1				
Bitternut hickory	81		4	4	4.9
Pin cherry	6				
Sugar maple	8309	97	182	85	1.0
Beech	307	2	4	2	0.7
Norway maple	2				
Hickory	5				
Totals:	10846	195	341	146	1.3

CONIFER SPECIES	Total No. Trees	Number of Dead Trees 1986	Number of Dead Trees 1987	Mortality 1987	1987 Mortality As Percent of Total Trees
Hemlock	83	3	7	4	4.8
White pine	20		3	3	15.0
Eastern white cedar	15	1	1		
Balsam fir	28	1	5	4	14.3
White spruce	8		2	2	25.0
Totals:	154	5	18	13	

Yearly Summaries	1986	1987
Total number of dead trees:	195	341
No. plots with dead trees:	78	100
Maximum dead trees per plot:	11	13
Average dead trees per plot:	2.5	3.4

Table 6 summarizes the additional tree quality observations recorded during the 1987 reassessment survey. Since the number of trees assessed for each species varies, the results are standardized by listing them as a percentage of the total number of trees affected for each tree species. Additional observations are summarized for both hardwood and coniferous species, and for comparative purposes, are listed in the same order as Table 2. Correlations of decline indices for sugar maple versus the additional tree quality observations showed only weak relationships (Table 7). Significant results are obtained for wounds, cankers, and swellings in the main stem. Percent insect defoliation and the sum of all tree quality observations are also highly correlated with the decline index. These data suggest that as a tree accumulates a number of quality defects, it may become more predisposed to decline from a variety of causes. However, individual tree quality defects are not well correlated with decline index, making it difficult to suggest cause and effect relationships.

Table 8 summarizes the mean decline indices for each hardwood species according to classes of diameter at breast height (DBH) from the 1987 survey results. There is little relationship between DBH and the decline index for each species. One might expect a trend for the smallest trees to have a somewhat higher decline index, due to suppression of these trees under the main canopy, and a trend for the largest trees to have somewhat higher decline indices, due to the

TABLE 6: Summary of additional tree quality observations by tree species, listed as a percentage of total trees affected, 1987.

HARDWOOD SPECIES	TOTAL NO. TREES	ADDITIONAL OBSERVATIONS									
		BROKEN STEM	WOUND	CRACK	OTHER HOLES	FUNGAL STRUCTURES	CANKERS	INSECTS	OTHER WOUNDS	SPROUTING	BARK SLOUGHING
White elm	8	0.0	37.5	0.0	0.0	0.0	0.0	62.5	0.0	0.0	100.0
Rock elm	2	0.0	0.0	0.0	0.0	50.0	0.0	100.0	0.0	50.0	100.0
White oak	4	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	25.0	50.0
Striped maple	3	0.0	0.0	33.3	0.0	33.3	0.0	66.7	0.0	33.3	66.7
Weeping willow	4	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	25.0
Bur oak	2	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	50.0	50.0
Black cherry	171	1.2	13.5	1.8	1.2	0.6	4.7	72.5	0.6	7.0	55.6
Balsam poplar	9	0.0	0.0	11.1	0.0	0.0	0.0	100.0	0.0	11.1	88.9
White birch	112	0.0	22.3	5.4	8.0	2.7	0.9	80.4	0.9	6.2	67.9
Trembling aspen	97	0.0	13.4	4.1	5.2	2.1	3.1	78.4	1.0	8.2	52.6
Red maple	313	0.3	24.3	10.9	3.2	2.6	2.9	85.9	0.3	20.4	42.8
Yellow Birch	175	0.6	21.1	21.7	6.3	3.4	3.4	86.9	0.0	13.7	59.4
Largetooth aspen	4	0.0	25.0	0.0	0.0	0.0	0.0	75.0	0.0	25.0	100.0
Ironwood	295	0.7	9.2	6.8	3.4	1.7	1.7	77.6	0.0	10.8	51.2
Black ash	28	0.0	25.0	0.0	3.6	7.1	0.0	82.1	0.0	3.6	67.9
Basswood	320	0.3	11.2	4.1	8.1	0.3	1.6	88.4	0.0	8.4	42.2
White ash	429	0.0	13.3	4.7	3.3	0.7	0.5	50.1	0.2	6.1	43.4
Northern red oak	156	0.6	7.7	7.7	5.8	1.3	0.6	84.6	0.0	6.4	30.8
Butternut	3	0.0	0.0	0.0	66.7	33.3	0.0	100.0	0.0	66.7	0.0
Tulip tree	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Bitternut hickory	81	0.0	13.6	2.5	0.0	0.0	0.0	38.3	0.0	7.4	29.6
Pin cherry	6	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	16.7
Sugar maple	8309	0.5	19.2	9.4	5.6	3.0	4.2	80.7	0.5	21.1	43.9
Beech	307	0.0	18.9	9.8	13.4	2.9	0.0	77.5	1.3	11.4	27.4
Norway maple	2	0.0	50.0	0.0	0.0	0.0	50.0	100.0	0.0	0.0	100.0
Hickory	5	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Weighted Averages:		0.2	12.5	5.1	5.1	5.6	2.8	71.6	0.2	15.1	54.3
Total No. Trees:	10846 (98.6%)										

CONIFER SPECIES	TOTAL NO. TREES	ADDITIONAL OBSERVATIONS									
		BROKEN STEM	WOUND	CRACK	OTHER HOLES	FUNGAL STRUCTURES	CANKERS	INSECTS	OTHER WOUNDS	SPROUTING	BARK SLOUGHING
Hemlock	83	1.2	4.8	3.6	13.3	1.2	2.4	43.4	1.2	1.2	3.6
White pine	20	5.0	30.0	0.0	0.0	0.0	0.0	25.0	5.0	5.0	5.0
Eastern white cedar	15	0.0	26.7	0.0	0.0	0.0	0.0	26.7	0.0	0.0	20.0
Balsam fir	28	7.1	3.6	0.0	0.0	0.0	0.0	10.7	0.0	0.0	21.4
White spruce	8	12.5	0.0	0.0	0.0	0.0	0.0	12.5	0.0	0.0	12.5
Weighted Averages:		5.2	13.0	0.7	2.7	0.2	0.5	23.7	1.2	1.2	12.5
Total No. Trees:	154 (1.4%)										

TABLE 7: Correlation between average sugar maple decline indices and number of additional tree quality observations recorded (as a percentage of the number of trees in each plot), 1987.

TREE QUALITY OBSERVATION	R VALUE	PROBABILITY LEVEL
BROKEN STEM		NS
WOUND	0.374	<0.001
CRACK		NS
OTHER HOLES		NS
FUNGAL STRUCTURES		NS
CANKERS	0.170	0.076
INSECTS		NS
OTHER WOUNDS		NS
SWELLING	0.166	0.084
SPROUTING		NS
BARK SLOUGHING		NS
% DEFOLIATION		<0.001

NS = non-significant

TABLE 8a: Mean decline index for each hardwood tree species by diameter class, 1987.

HARDWOOD SPECIES	NO. TREES	DECLINE INDEX BY DBH CLASSES (CM)								
		10-<15	15-<20	20-<25	25-<30	30-<35	35-<40	40-<45	45-<50	50+
Sugar maple	8309	14	13	12	13	13	13	16	14	14
White ash	429	16	19	14	16	15	15	18	16	14
Basswood	320	19	17	14	21	22	20	20	16	25
Red maple	313	28	24	26	17	19	18	22	15	21
Beech	307	12	14	12	11	12	17	13	10	11
Ironwood	295	14	14	15	21	23				
Yellow birch	175	24	19	15	24	14	19	26	18	21
Black cherry	171	43	30	26	18	22	18	15	29	27
Northern red oak	156	12	14	14	16	14	20	13	12	20
White birch	112	20	19	23	18	20	24	23	23	56
Trembling aspen	97	13	25	21	17	21	14	19	31	
Bitternut hickory	81	22	9	20	9	10	12	10	5	11
Black ash	28	22	16	25	15	21	25	33		
All Tree Species:	10843	21	19	18	18	17	20	21	18	19

TABLE 8b: Number of trees within each DBH class, to assess the reliability of mean decline index values in each cell.

HARDWOOD SPECIES	NO. TREES	10-<15	15-<20	20-<25	25-<30	30-<35	35-<40	40-<45	45-<50	50+
Sugar maple	8309	1695	1814	1551	1121	808	548	315	171	194
White ash	429	52	65	81	57	79	33	20	10	13
Basswood	320	34	41	59	54	55	36	26	18	9
Red maple	313	57	84	72	56	30	14	10	5	8
Beech	307	78	33	46	54	39	35	22	17	9
Ironwood	295	197	67	22	7	2	0	0	0	0
Yellow birch	175	13	24	32	23	21	21	15	13	18
Black cherry	171	20	29	38	36	16	16	5	6	8
Northern red oak	156	1	22	31	24	26	17	14	7	17
White birch	112	10	18	22	30	14	4	6	5	3
Trembling aspen	97	5	16	15	10	14	7	4	3	0
Bitternut hickory	81	5	7	18	26	22	7	5	4	1
Black ash	28	8	11	6	9	2	2	1	0	0
All Tree Species:	10843	2206	2282	2031	1540	1163	759	457	271	290

accumulation of quality defects associated with overmaturity. However, these trends are not statistically significant. Also, the relationship between DBH and age of hardwood species is poor, since growth varies considerably depending on soil, site and climatic factors both within and between stands. Decline indices are distributed relatively evenly amongst all DBH classes for all species, indicating that decline is a phenomenon distributed relatively evenly through the forest stand, and is not simply a phenomenon restricted to the very largest trees, or to suppressed trees in the understory.

5.3 Trends in Decline Indices Within Imposed Boundaries

In order to assess regional patterns in the distribution of the decline index, decline indices were summarized for the Ontario Ministry of Natural Resources administrative Districts, Forest Sectors (Rowe 1972) and for wet sulphate deposition zones (Tang et al 1986). Table 9 lists the mean decline indices for sugar maple and for all tree species combined for 1987, for each of the OMNR administrative districts, in decreasing order of average decline index. Average decline index for all tree species combined exceeds 20 in the Algonquin Park, Bracebridge, Sudbury, Espanola, and Pembroke Districts. Average decline indices for all tree species are very low (less than 10) in the Tweed, Maple, Carleton Place, Lindsay, Napanee and Brockville Districts.

TABLE 9: Average decline indices for sugar maple and all tree species combined for each OMNR Administrative District, 1987.

OMNR DISTRICT	NUMBER OF PLOTS	AVERAGE DECLINE INDEX: SUGAR MAPLE	AVERAGE DECLINE INDEX: ALL TREE SPECIES
ALGONQUIN PARK	4	26	26
BRACEBRIDGE	4	23	26
SUDBURY	2	18	22
ESPANOLA	5	19	21
PEMBROKE	2	20	20
NORTH BAY	3	17	19
SAULT STE. MARIE	3	16	18
NIAGARA	2	15	18
PARRY SOUND	3	16	18
AYLMER	4	15	18
BANCROFT	7	14	16
CAMBRIDGE	8	14	16
BLIND RIVER	5	13	15
MINDEN	2	13	15
OWEN SOUND	5	11	15
CORNWALL	2	13	15
SIMCOE	5	11	14
WINGHAM	5	12	14
CHATHAM	7	12	13
HURONIA	7	11	13
THUNDER BAY	2	13	13
WAWA	5	13	12
TWEED	2	7	8
MAPLE	5	6	7
CARLETON PLACE	3	8	7
LINDSAY	3	5	7
NAPANEE	1	4	5
BROCKVILLE	4	2	3

The hardwood decline survey plots are located in two Forest Regions in Ontario, and eight Forest Sectors (Rowe 1972). Mean decline indices for all tree species combined are summarized for each Forest Sector in Table 10. The Tukey-Cramer test, a modification of Tukey's honestly significant difference (HSD) multiple comparison test, was used to assess differences between the Forest Sectors (Table 10). This test adjusts for the unequal number of plots in each Forest Sector using a harmonic mean. Similar multiple comparison tests, including Fisher's LSD, Duncan's multiple range, and Newman-Keuls tests, require that the counts of cases per group be equal, since the Type 1 error rates of these procedures when adjusted for unequal sample sizes are unknown (Miller 1985). Tukey's HSD and the adjusted Tukey-Cramer test is generally preferred to the other methods in the statistical literature (Wilkinson 1988).

Forest Sector 2 (Upper St. Lawrence) has the lowest mean decline index of 8.8. Forest Sector 4E (Sudbury-North Bay), has the highest mean decline index at 22.3. Forest Sector 1 (Niagara-Huron), 10 (Sault Ste. Marie-Algoma), 11 (Thunder Bay-Quetico), and 4C (Middle Ottawa) have intermediate mean decline indices that are not significantly different from each other. Significant differences occur only between the areas of lowest decline index (Sector 2 (Upper St. Lawrence) and the areas of highest decline index (Sector 4B (Algonquin-Pontiac), Sector 4D (Parry Sound-Georgian Bay), and (Sector 4E (Sudbury-North Bay)).

TABLE 10: Results of multiple comparison test (Tukey-Cramer HSD) between Forest Sectors for plot average decline indices, for all tree species.

ANALYSIS OF VARIANCE

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	PROBABILITY
BETWEEN GROUPS	1254.216	7	179.174	4.471	<0.001
WITHIN GROUPS	4087.326	102	40.072		

TUKEY-CRAMER MULTIPLE COMPARISONS
MATRIX OF PAIRWISE COMPARISON PROBABILITIES

FOREST SECTOR	1	10	11	2	4B	4C	4D	4E
1	1.000							
10	1.000	1.000						
11	1.000	0.996	1.000					
2	0.246	0.490	0.701	1.000				
4B	0.815	1.000	0.698	0.001	1.000			
4C	1.000	0.994	1.000	0.420	0.528	1.000		
4D	0.984	1.000	0.936	0.003	0.997	0.864	1.000	
4E	0.071	0.837	0.062	0.000	0.812	0.015	0.298	1.000

RANKED FOREST SECTORS	NUMBER OF PLOTS	MEAN DECLINE INDEX	STANDARD DEVIATION	LOCATION	GROUPINGS
4E	12	22.3	5.1	Sudbury - North Bay	A
4B	15	18.3	8.0	Algonquin - Pontiac	A B
4D	12	16.6	6.2	Parry Sound - Georgian Bay	A B
10	11	16.4	4.3	Sault Ste. Marie - Algoma	A B C
1	40	14.2	5.2	Niagara - Huron	A B C
11	3	13.2	3.0	Thunder Bay - Quetico	B C
4C	7	13.2	11.5	Middle Ottawa	B C
2	10	8.8	6.9	Upper St. Lawrence	C

GROUPINGS: Forest Sectors linked by letter bars are not significantly different with respect to decline indices.

Decline index means were also calculated for the plots falling within zones of wet sulphate deposition (Table 11). The deposition zones were based on mean wet sulphate deposition in Ontario, from 1981 to 1984, in kilograms per hectare per year (Figure 8). Differences in the mean decline indices for sugar maple between wet sulphate deposition zones, were tested statistically using the Tukey-Cramer multiple comparison test. Although significant differences with respect to decline index between loading zones can be distinguished with the Tukey-Cramer test, increasing decline indices are not consistently related with increasing levels of sulphate deposition. The loading zones with the highest average decline index correspond geographically to those which were heavily defoliated in 1987 by the forest tent caterpillar. In addition, the effects of the various levels of wet sulphate deposition on decline index will be expected to vary according to local site and stand conditions, including the soils' buffering capacity, the nature and structure of the forest stand, and other stress factors acting upon the ecosystem. Direct relationships between pollution loading levels and decline index cannot be established from the results of this survey, given the complexity of the relationship between these factors and the nature of the survey.

TABLE 11: Results of multiple comparison (Tukey-Cramer) test for differences of means for 1987 sugar maple decline indices within wet sulphate deposition isopleths.

ANALYSIS OF VARIANCE

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	PROBABILITY
BETWEEN GROUPS	602.780	6	100.463	2.185	0.005
WITHIN GROUPS	4735.740	103	45.978		

TUKEY-CRAMER MULTIPLE COMPARISONS
MATRIX OF PAIRWISE COMPARISON PROBABILITIES

SO4 DEPOSITION (KG/HA/YR)	>35	30-35	25-30	20-25	15-20	10-15	<10
>35	1.000						
30-35	0.996	1.000					
25-30	1.000	0.998	1.000				
20-25	0.986	0.007	0.976	1.000			
15-20	0.605	0.001	0.551	0.496	1.000		
10-15	0.969	0.995	0.981	0.011	0.001	1.000	
<10	1.000	1.000	1.000	0.930	0.421	0.996	1.000

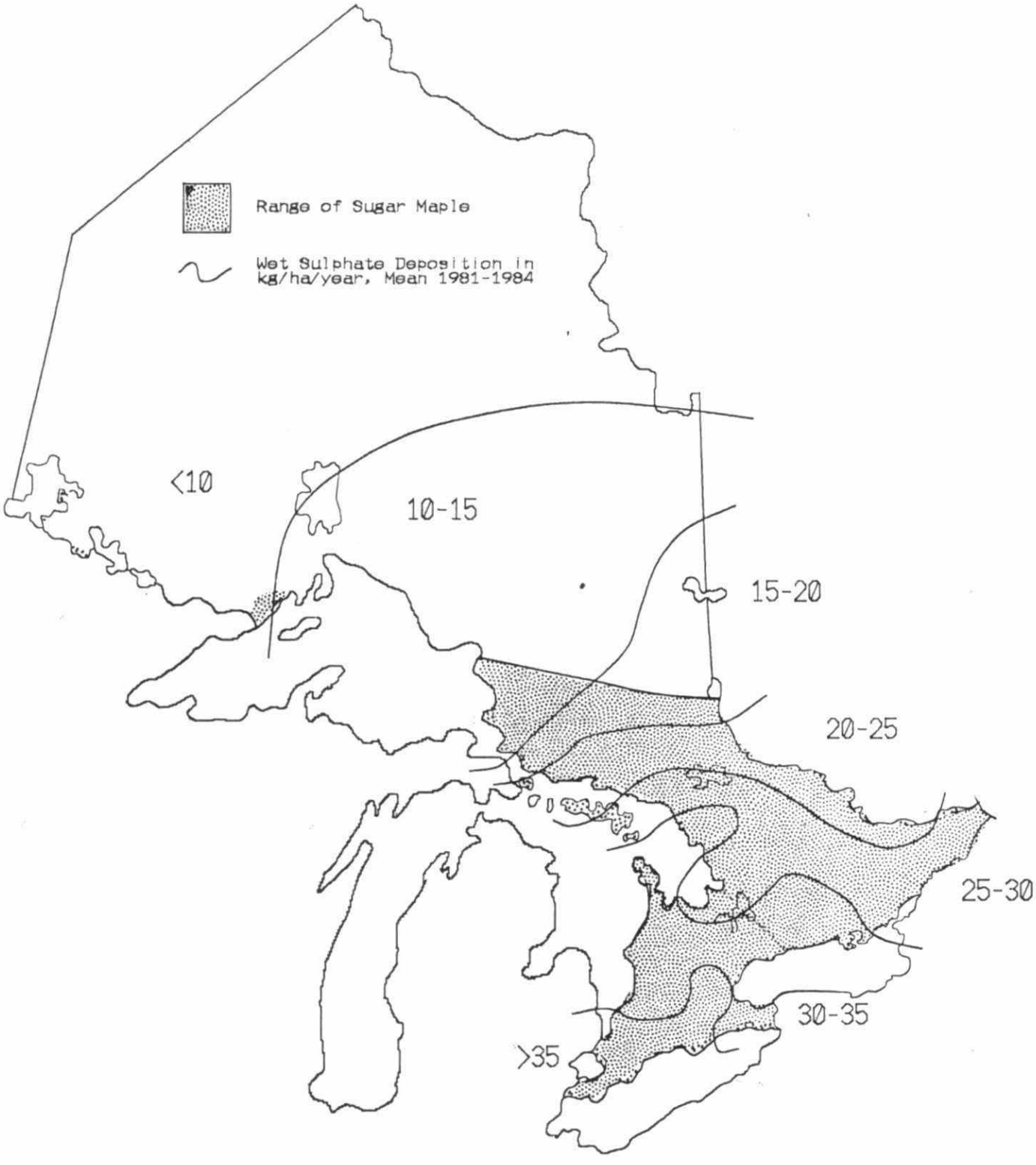
SUMMARY STATISTICS FOR 1987 DECLINE INDEX

SO4 DEPOSITION (KG/HA/YEAR)	>35	30-35	25-30	20-25	15-20	10-15	<10
NO. PLOTS	10	34	41	16	3	3	3
MEAN	14.0	11.4	13.6	17.1	21.7	10.1	12.7
STDDEV	4.7	5.6	7.9	8.0	3.8	3.7	2.6

RANKED MEAN DECLINE INDEX	SO4 DEPOSITION (KG/HA/YEAR)	GROUPINGS	
10.1	10-15	A	
11.4	30-35	A	
12.7	< 10	A	B
13.6	25-30	A	B
14.0	> 35	A	B
17.1	20-25		B
21.7	15-20		B

PLOTS WITHIN THE 10-15 AND 30-35 KG/HA/YR ISOPLETHS ARE DIFFERENT FROM PLOTS WITHIN THE 20-25 AND 15-20 KG/HA/YR ISOPLETHS.

FIGURE 8: The range of sugar maple in Ontario (Hosie 1975) and the average wet sulphate deposition over the four year period 1981 to 1984 (Tang et al. 1986).



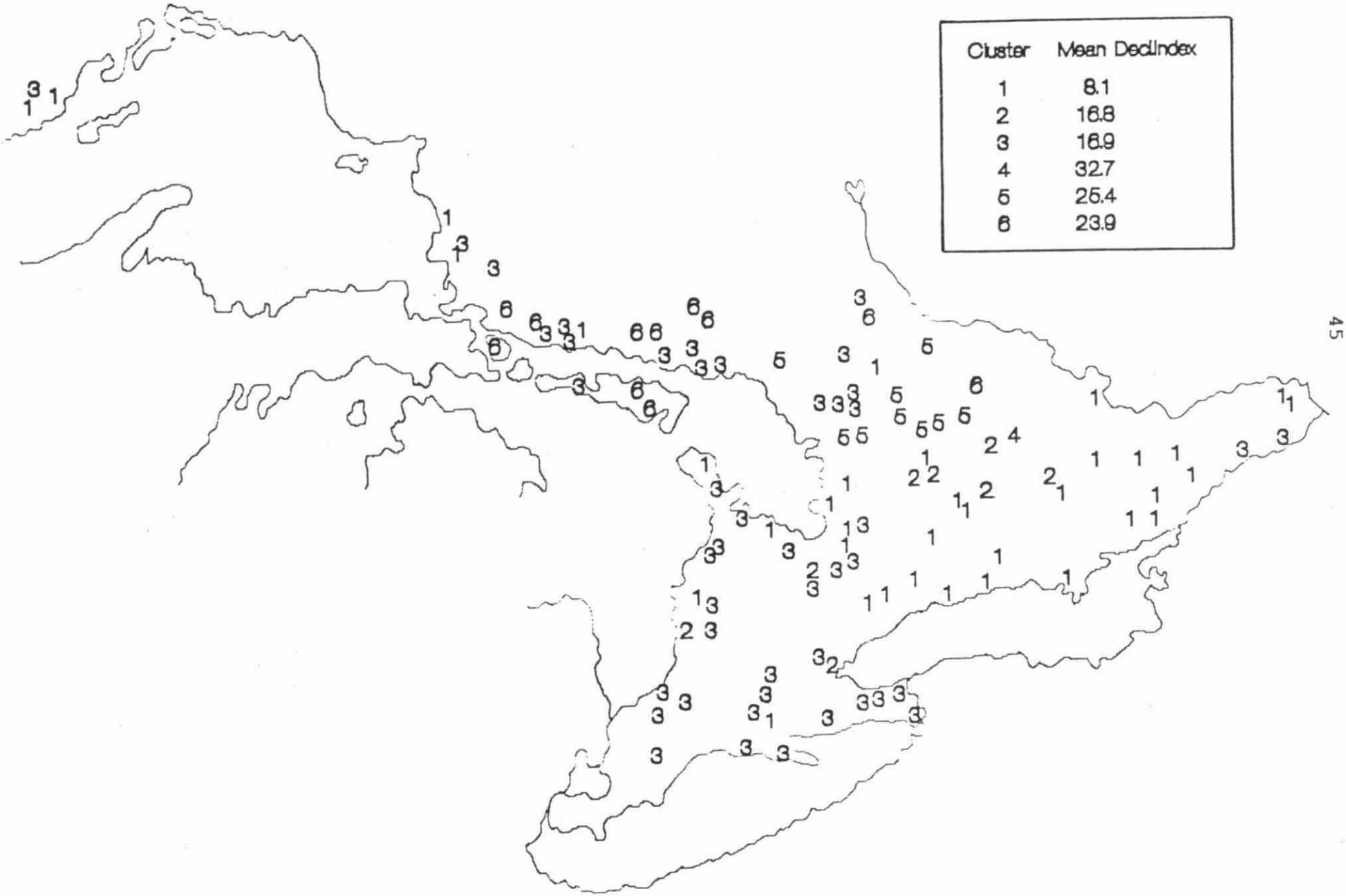
5.4 Classification of Plots Using K-Means Cluster Analysis

An alternate approach to assessing regional patterns of decline index is through the use of multivariate classification techniques for forming groups from the plot data. Accordingly, K-means cluster analysis (Wilkinson 1988) was used to form six groups of plots. The K-means technique allows one to select the attributes to be used in the grouping, and to define the resulting number of groups formed. Plots are then classified into each of the specified number of groups such that variation within groups is minimized relative to the variation between groups. The groups formed in this manner may not necessarily be statistically different.

The K-means cluster analysis was performed using seven decline attributes: percent dead large branches, percent dead twigs, slight and strong chlorosis, percent small leaves, percent necrosis and percent insect defoliation. The decline index values are calculated from the former attributes and were therefore not included in the analysis. The number of groups formed (6) was chosen to be consistent with the K-means analysis performed on the previous year's data as part of the report on the 1986 survey.

The geographic distribution of the six groups formed by the K-means cluster analysis is illustrated in Figure 9. Group 4 consists of only one plot, which was severely defoliated and has a very high decline index, located in the Algonquin area. Group 5 consists of the heavily defoliated plots in the Algonquin, Parry Sound, North Bay

FIGURE 9: K-means cluster group membership, formed using 1987 decline attributes for all tree species, for the 110 Hardwood Decline Survey plots in Ontario.



area and has a relatively high average decline index of 25.4. Group 6 is centered in northern Ontario, mostly along the north shore of Lake Huron. Several of the plots correspond to the plots in that area which are heavily defoliated. Groups 1,2 and 3 are distributed throughout the study area. Many of the plots for Group 1, which has the lowest mean decline index of 8.1, are located in central and eastern Ontario.

In summary, the cluster analysis reveals that plots of both high and low decline index occur in all parts of the province. However, areas of highest decline index are centered about those areas which have experienced insect defoliation, primarily in northern Ontario. The area of lowest decline index is centered on central and eastern Ontario. Coincidentally, this corresponds to the portion of Ontario on a limestone base with deep, well buffered calcareous soils. The plots located in southwestern Ontario, corresponding to the area of highest wet sulphate and ozone loadings, typically show an intermediate decline index similar to many of the nondefoliated plots in northern Ontario.

Tukey-Cramer's multiple comparison test revealed three significantly different groups from amongst the six clusters with respect to decline indices. Plots with the lowest average decline index occurred in cluster group 1 (mean decline index of 8.1). Plots in this group are significantly different from those in clusters 2 and 3 (mean decline indices of 15.8 and 16.9 respectively). Both

previous groups are significantly different from clusters 5 and 6 (mean decline indices 23.9 and 25.4 respectively). Cluster 4 was not included in the analysis since it has only one member. Significant differences between the cluster groups with respect to decline index are summarized in Table 12.

TABLE 12: Results of multiple comparison test for mean 1987 decline indices (all tree species) between the six groupings formed by K-means cluster analysis.

TUKEY-KRAMER HSD MULTIPLE COMPARISONS FOR DECLINE INDEX BETWEEN CLUSTERS

ANALYSIS OF VARIANCE

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	PROBABILITY
BETWEEN GROUPS	3721.109	4	930.277	73.173	<.001
WITHIN GROUPS	1322.186	104	12.713		

MATRIX OF PAIRWISE COMPARISON PROBABILITIES

CLUSTER NUMBER	1	2	3	5	6
1	1.000				
2	0.000	1.000			
3	0.000	1.000	1.000		
5	0.000	0.000	0.000	1.000	
6	0.000	0.001	0.000	0.902	1.000

RANKED CLUSTER GROUPS

CLUSTER NUMBER	MEAN DECLINE INDEX	GROUPINGS
1	8.1	A
2	16.8	B
3	16.9	B
6	23.9	C
5	25.4	C

Three significantly different groups emerge: cluster 1, clusters 2 and 3, and clusters 5 and 6. Cluster 4 has only one member (plot decline index = 32.7), and hence, was not included in the analysis.

Although some cluster groups are not significantly different with respect to decline index, differences in the mean values for the decline attributes used in the cluster analysis are apparent (Table 13). Groups 2 and 3 are not different with respect to decline index,but were differentiated by the cluster analysis on the basis of higher insect defoliation and percent early fall colouration for the plots in cluster 2. Clusters 5 and 6 are also not different with respect to decline index, but were differentiated by the K-means analysis on the basis of differences in slight chlorosis and early fall colour, which are significantly higher in group 5.

TABLE 13: Summary of average values for 1987 decline attributes for all tree species: a description of the six groups groupings formed by K-means cluster analysis.

CLUSTER NUMBER	NUMBER OF PLOTS	DECLINE INDEX	% LARGE DEAD BRANCHES	% DEAD TWIGS	% STRONG CHLOROSIS
1 .	36	8.1	7.2	7.8	1.9
2 .	8	16.8	14.8	16.5	4.2
3 .	45	16.9	17.4	13.6	2.6
4 .	1	32.7	38.4	21.9	6.4
5 .	9	25.4	27.0	16.0	8.7
6 .	11	23.9	29.0	12.5	10.8

CLUSTER NUMBER	% SLIGHT CHLOROSIS	% EARLY FALL COLOUR	% SMALL LEAVES	% NECROSIS	% INSECT DEFOLIATION
1 .	1.1	2.2	0.2	1.4	3.3
2 .	1.6	37.7	0.1	1.3	17.6
3 .	6.6	4.2	0.8	1.0	4.4
4 .	8.5	42.3	3.2	3.3	42.5
5 .	16.2	18.3	2.5	2.5	27.9
6 .	7.3	4.0	1.4	1.0	26.9

6.0 SUMMARY

Plot average decline indices for 1987 for sugar maple and for all tree species combined correlated well with patterns of insect defoliation throughout Ontario. In the Algonquin, Parry Sound, and Muskoka areas, many of the plots increased in decline index relative to the 1986 survey. In general, increases in decline index tended to correspond to the severe infestation of forest tent caterpillar and other agents, including the Bruce Spanworm, during the 1986 and 1987 growing seasons. Several plots along the north shore of Lake Huron also increased in decline index. This area was subject to local, severe infestations of the forest tent caterpillar in 1987. Plots in southwestern Ontario (especially in the Niagara and London areas), and in eastern Ontario (especially in the Cornwall area) also increased in decline index. Several plots in this area of Ontario corresponded to mapped sightings of egg masses, which usually lead to localized infestations of the gypsy moth. Maps of insect defoliation patterns in Ontario, and egg mass sightings for Gypsy Moth in southwestern Ontario for 1987 are included in Appendix 7.

Several plots in eastern and central Ontario showed a decrease in the decline index. This apparent recovery of these stands may be related in part to the collapse of the gypsy moth populations in this area. Several plots in this area with a relatively high decline index in 1986 were located within areas severely defoliated in the previous year (Ingram 1986).

Other than the plots corresponding to areas of severe defoliation, average decline indices for 1987 were very similar to the results from the 1986 survey. For the majority of the non-defoliated plots, the decline indices changed less than one standard deviation:

Change in Decline Index	Number of Plots	Percent of Plots
decrease more than 1 SD	11	10
no change	74	67
increase more than one SD	25	23

This suggests that decline index mapping is repeatable from year to year, and supports the validity of the assessment procedures used.

Currently, 3.4% of the trees in the Hardwood Decline plots are dead. Approximately 1.3% mortality has occurred since the 1986 survey. At present, there are no provisions made to account for mortality and ingrowth within the plots, since each plot consists of a fixed number of trees. To allow for mortality and ingrowth in future surveys, the plots must be changed to a fixed area to encompass a changing number of trees over time, rather than a fixed number of trees.

The strongest correlations of the mean decline indices for 1987 are with insect defoliation levels within the plots. Correlations with the additional tree quality observations are weak. There are no consistent patterns that are discernible with respect to wet sulphate deposition within the study area. The patterns that were discerned

with respect to Forest Sectors can mostly be attributed to defoliation patterns, with the following exceptions. There is a general trend for the northern Ontario plots to have a higher decline index than the plots located in southern Ontario. This is probably related to macroclimatic and soil differences. Within southern Ontario, the plots located in the highest pollution loading area (especially the Aylmer, Cambridge, and Niagara Districts) have higher decline indices than plots located in the central and eastern portions of southern Ontario, where climate and soil conditions are similar.

This pattern may reflect differences in stand management, since few large hardwood stands remain in southwestern Ontario. The stands in which the plots are located have been utilized for a variety of purposes, such as tapping for maple syrup production and fuelwood cutting, for a longer period of time compared with more northerly locations. Direct cause and effect relationships between decline index and pollution loading levels were not possible to establish from the results of this survey, although this was not an objective.

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APPENDIX 1

General layout of Hardwood Decline Plots, and maps of tree numbers and locations within the individual Hardwood Decline Survey plots

(Bound Separately)

APPENDIX 2

GUIDE TO COMPLETION OF TREE CONDITION ASSESSMENT FORMS
PERMANENT OBSERVATION PLOTS
HARDWOOD DECLINE SURVEY IN ONTARIO

APPENDIX 2

GUIDE TO COMPLETION OF TREE CONDITION ASSESSMENT FORMS PERMANENT OBSERVATION PLOTS HARDWOOD DECLINE SURVEY IN ONTARIO

Prepared by:

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Phytotoxicology Section
Air Resources Branch
Ontario Ministry of the Environment

Header Information

Date: Enter the day, month and year that the assessment was completed.

Surveyors: Enter the name(s) of the person(s) who made the actual ratings of the trees' condition.

Site Number: This is the number which has been assigned to the plot (i.e. A-056).

Weather: Briefly indicate the prevailing conditions for the time of the assessment (e.g. sunny, scattered cloud, drizzle, rain, etc.).

Location: Enter a name which will serve to easily identify the site. This can be the name of the Conservation Area, Provincial Park, Township, landowner's name or the name of a nearby urban centre.

Assessment Data

Data for each tree are to be entered under the appropriate column identified on the form. Each tree will utilize a separate row of data on the form and a sufficient number of pages must be completed to evaluate all trees on the plot (the assessment form shown in Figure 3 would require seven pages per plot).

Tree Number: Enter the number assigned to the tree as indicated by the tag or number marked on the tree in the plot. The last two digits are those of greatest importance. To avoid confusion, trees should be evaluated in numerical sequence.

Species Code: The tree species codes are standard codes used by the Ministry of Natural Resources for forest inventory, and consist of a pair of letters representing the initials of the species common names (Appendix D). Some species are grouped together under a single code for inventory purposes. In these cases, and

appropriate new code can be employed, for example, 'Pt' for trembling aspen and 'Pb' for balsam poplar. Coding should be consistent and special codes should be documented.

DBH: Measure the diameter of the tree at breast height using standard techniques. The DBH measurement point should be marked with paint on each tree. Accuracy of the measurement should be to the nearest centimeter. Diameter tapes are more accurate for the measurement of irregularly shaped hardwoods than tree calipers.

Tree Height: Total height of the tree is measured from the top of the highest living branch to ground level using standard techniques (e.g. Abney, Haga or Suunto clinometer). Accuracy to the nearest metre is required.

Height to Lowest Branch: Height to the base of the living crown is measured in the same manner as total tree height. Sucker growth and inconsequential small branches are disregarded. For those trees which have crowns which are substantially reduced in size or which are composed largely of epicormic branches, the base of the crown is considered to be the lowest living branch contributing to the mass of the crown.

Crown width: Crown width is determined by measuring the distance (in metres) of the drip line from the center of the tree in two directions. It is suggested that the distances be measured in the north and south directions from the tree bole. Other directions are equally acceptable as long as the observer is satisfied that the distance is representative of the tree canopy and the direction is also noted on the form (i.e. NE, WSW, etc.). In certain cases, it may be impossible to determine the drip line for some trees. In these instances, the observer should make a best estimate of the position of the drip line and indicate this in brackets on the form. Crown width is used for producing accurate plot maps, and may be useful determining a tree's health or competitive interactions with its neighbours.

Percent Dead Branches: Dead branches are scored according to two size classes (large branches and twigs).

Large branches are either primary or secondary branches with a diameter of 10 cm or greater at their point of attachment. They are considered to be dead only if all of their respective terminal portions lack foliage. The percentage of dead branches is determined by comparing the numbers of dead branches with the total number of branches in the tree which fall within this size category. Dead branches which have resulted from the phenomenon of self-shading are not considered in this calculation.

Small branches are those less than 10 cm in diameter at their point of attachment. Branches lacking all foliage in the distal portions will be considered to be dead. Estimates of the percentage of all

branches which are dead in this size category will be made. These estimates exclude from consideration all smaller branches and twigs associated with large dead branches (above) and branches which have died as a result of self-shading.

Chlorosis Ratings: Normal maple foliage is a medium to dark green when healthy. Certain trees have foliage which is paler or more yellow due to lack of chlorophyll. Experienced observers can recognize this yellowed or chlorotic condition despite the lack of objective methods for evaluating the condition. Several factors, especially sunshine, can alter the perception of the degree of chlorosis; however, an estimate of the chlorosis can be made by comparison of chlorotic tissues with adjacent healthy tissues. Estimates of the percentage of all leaves present on a tree with either a slight chlorosis or a strong chlorosis are made, and are recorded in the appropriate data columns. Standard colour scales are available (e.g. photographic scales) which may help to evaluate the chlorosis rating.

Early Fall Colour: Fall colouration of sugar maple foliage can vary from yellow to orange, red, purple or brown. Healthy foliage does not develop these colours until at least mid-September. The appearance of these colours prior to this time indicates a problem of some nature. The degree of development of the fall colouration is estimated and recorded as the percentage of all foliage which has developed any fall colour. In most cases, strong chlorosis will be reflected as early fall colour.

Percent Necrosis: Record percentage of all foliage which has become necrotic (tissues which are dead).

Crown Class Rating: Record the rating of overall crown condition according to the scale 1 to 10, as indicated in Appendix C.

Percent Defoliation: Numerous species feed on the foliage of sugar maple and other hardwoods (Rose and Lindquist, 1982). Trees may be defoliated up to 100% by various insects during local infestations. Although refoliation will likely occur prior to most tree assessments, in some instances the defoliation may preclude an accurate assessment of tree condition. The degree of loss of foliage is estimated as a percentage of that which would be expected for a full canopy. Trees that are severely defoliated (greater than 60-80% of the crown) should not be assessed for chlorosis and other attributes of the leaves.

Additional Observations

The foregoing observations are generally those which contribute to the calculation of various indices of decline. The diagnosis of the cause of any problem may be aided by interpretation of a set of additional observations primarily related to pests, diseases, or other injuries. These are recorded mainly as presence or

absence in the appropriate column. A simplified coding system for the additional observations is presented at the end of this Appendix.

Miscellaneous and Main Stem Injuries

Severe injuries on the main stem of a tree may be responsible for the symptoms in the crown. It is difficult to predict which injury, if severe enough, could lead to the development of symptoms which could be observed in the crown. For this reason, any readily observable symptoms will be recorded since they could aid in the diagnosis of any future problem with the tree. Causal agents will be identified when possible and the level of confidence will be indicated by the method of identification.

Definition and Recognition of Main Stem Injuries

1. Broken Stem: obvious signs of breakage to complete separation of the stem. One or more of the following agents, especially decay organisms, may be involved.

2. Wound: woody tissues exposed in an area larger than 2.4 cm in diameter caused by mechanical means. In many instances, the cause of fresh injury may be diagnosed to an agent such as an axe, machinery or a fallen tree or branches.

3. Crack or Seam: a wound or canker which may be healed, that is at least five times longer than wide. Some causes can be diagnosed as follows:

   Lightning - a long scar or crack in the trunk leading to the base of the tree, often in a spiral pattern about main stem.

   Frost - crack(s) in the main stem caused by differential thawing and freezing following extremes in temperature. The cracks can be extensive but are usually confined to the main stem. In many cases, a center line of continued cracking surrounded by a callus ridge may form and extend out from the normal bark surface.

Holes: openings which penetrate over 1 cm into the wood tissue of the stem. Several types of holes are recognizable:

4. Tap Holes Healed: Tapping of trees to obtain sap is evident as uniform openings 1.3 cm in diameter. Old tap holes may be difficult to recognize since the bark may split during expansion of the bole diameter, however, the roundness of the edge of the hole may still be evident in the bark.With time the hole may become occluded or healed by the growth of callus tissue around the opening. Such a hole considered to be healed if the callus completely covers the opening. The numbers of healed tapping holes are recorded.

5. Total Tap Holes: The total number of healed and unhealed tap holes are also recorded.

6. Other Holes:

Woodpeckers may create holes in the bark and woody tissues of the trees during feeding or nest building activity. These may be recognized as three distinct types:

Pileated Woodpecker which causes very large openings (over 5 cm in diameter and up to 1 m in length, generally in decaying wood).

Yellow-belled Sapsucker: which makes fairly shallow holes to the cambium, about 5 mm in diameter and arranged in a series of rows.

Other woodpeckers: make circular holes usually less than 5 cm in diameter.

Insects such as ants or wood borers may create holes which penetrate deeply into the wood or cambium and are usually only a few mm wide. Insect frass is often in or below the openings.

A variety of other types of holes may be present and may cover a wide range in size. In many cases, these openings mark the former position of branches of different sizes. Decay of the branch stub formed an opening and frequently indicates that the main bole has a heart rot condition.

7. Fungal Structures: rhizomorphs or fruiting bodies such as conks and mushrooms present on the stem or base of the tree.

8. Cankers: are the result of infection of disease organisms. They generally cause some disruption of normal growth and are associated with death of some of the living tissue. Some cankers have characteristics which allow for diagnosis of the causal agent in the field. Others require isolation of the causal agent using laboratory techniques. The following are the more common canker diseases of sugar maple:

1. Nectria galligena: distinctly target shaped cankers usually centered around a dead branch stub. Target shape caused reinvasion of callus tissue in succeeding years. Causal fungus appears as bright red perithecia on the edge or within ridges of most recent callus folds. Canker appears flared out from opposite side.

2. Fusarium solani: Annual cankers distinguished from perennial species by lack of repeated callus growth. Often

elongated in shape and may be sunken if recently formed. Older infections may be raised due to formation of callus folds over the infected area, often forming a "T" shape closing in cross section.

3. Eutypella parasitica: Distinctive due to large size and flared, flattened trunk surface on side of trunk opposite infection. Callus folds may exceed tree width. Irregular in shape with sloughed bark and decaying wood behind cankered surface.

4. Schizoxylon microsporum: Rare canker, irregular lesions with outer callus folds remaining covered by bark; white mycelial fans under bark at canker margins.

5. Phytophthora cactorum: Bleeding canker, elongate to over a metre in length, often to ground line. Cankers with sunken dead bark which secretes red to black fluid. Underlying tissues may be stained red with green edge. Cankers appear one above another rather than spread around the tree.

6. Other Cankers: Cankers may be produced by other species of fungi including Stereum murrayi, Daedalea unicolor and Polyporus glomeratus. These will be recorded as other cankers unless they are present in numbers which warrant individual attention.

9. Insects: Damage caused by insect feeding activity is not usually of concern unless the tree is already in a poor condition when the pests become more aggressive. Other than leaf feeders, the most conspicuous species which is associated with sugar maple is the sugar maple borer (Glycobius speciosus) which tunnels under the bark of declining trees. The gall making maple borer (Xylotrechus aceris) and the pitted ambrosia beetle (Corythylus puntissimus) both bore into the wood of the stem and must be removed from the tree for identification.

10. Other Wounds: Bark of the trees may be damaged by the feeding of animals such as rodents. When fresh, the cause of these wounds can be determined by the teeth marks which remain visible.

11. Swelling: enlargement of the trunk greater than one-tenth of the diameter of the trunk.

Sprouts: are formed mainly as the result of activity of adventitious buds at different locations on the stem. Frequently these develop in response to (or immediately following) the death of more distal parts of the tree as epicormic sprouts. In following the etiology of declines and possibly to aid in diagnosis of the cause of the decline, the location and abundance of the

sprouts will be recorded.

12. Sprout Location:
    1. Basal area (below 2 m) on main steam
    2. On main stem above 2 m
    3. On major branches (> 15 cm diam)
    4. On minor branches (< 15 cm diam)

13. Abundance:
    1. Only a limited number present (less than 10)
    2. Moderate number of sprouts present (10 to 100)
    3. Copious sprout development (more than 100)

14. Bark Sloughing: Bark death provides some indication of the timing or nature of the cause of death of the branches in the tree crown. On dead branches, the sloughing of bark will be rated as follows:

    1. Bark mostly held tightly to the branch
    2. Bark sloughing in long stringy strips

The former class indicates that the branch death occurred late in the season or during the dormant period. The second class is an indication that the bark death occurred early in the growing season when the cambium was active (slipping stage).

Others: Additional factors affecting a tree's health may be observed. These should be specifically identified and their presence recorded in the appropriate columns. Examples of other observations include suppression and double or multiple main stem formation.

SIMPLIFIED GUIDE TO DATA CODING FOR ADDITIONAL OBSERVATIONS

1. Broken Stem
   0. Healthy stem
   1. Broken stem

2. Wound
   0. No wounds
   1. Wound(s) present

3. Crack or Seam
   0. None
   1. Lightning
   2. Frost cracking

4. Tap Holes Healed
   Count and record actual number

5. Tap Holes Total
   Count and record actual number

6. Other Holes
   1. Woodpecker holes
   2. Insect holes
   3. Others

7. Fungal Structures
   0. None
   1. Rhizomorph
   2. Mushroom
   3. Conk

8. Canker
   0. None
   1. Nectria
   2. Fusarium
   3. Eutypella
   4. Other

9. Insects
   0. None
   1. Maple Borer
   2. Gall Borer
   3. Ambrosia Beetle
   4. Other

10. Other Wounds
    0. None
    1. Rodents

11. Swelling
    0. None
    1. Present

12. Sprout Location:
    1. Basal area (below 2 m) on main steam
    2. On main stem above 2 m
    3. On major branches (> 15 cm diam)
    4. On minor branches (< 15 cm diam)

13. Sprout Abundance:
    1. Only a limited number present (less than 10)
    2. Moderate number of sprouts present (10 to 100)
    3. Copious sprout development (more than 100)

14. Bark Sloughing:
    1. Bark mostly held tightly to the branch
    2. Bark sloughing in long stringy strips

15. Other:
    Specify at bottom of tally sheet in field notes, and record presence or absence of the factor as 1 or 0.

16. Other
    Specify at bottom of tally sheet in field notes, and record presence or absence of the factor as 1 or 0.

APPENDIX 3

CROWN CLASSIFICATION SYSTEM
FOR CONIFEROUS AND DECIDUOUS TREES

APPENDIX 3

CROWN CLASSIFICATION SYSTEM FOR CONIFEROUS AND DECIDUOUS TREES

1. Very high quality tree with nearly perfect form and no apparent defects, pests or disease, usually open grown, with the crown free from overlapping by the crowns of adjacent trees.

2. High quality forest tree with good form and no obvious defects, in an uniform stand with self pruning of shaded branches.

3. Tree in good condition, but with 1 or 2 dead branches not totalling more than 10% of the branches in the crown.

4. Tree in fair to moderate condition with 3 or more dead branches, not totalling more than 25% of the branches in the crown.

5. Tree in fair to poor condition with 26-50% of the branches in the crown dead.

6. Tree in poor condition with 51-75% of the branches in the crown dead.

7. 76-90% of the crown dead.

8. Over 90% of crown dead, with remaining branches retaining foliage.

9. Branches retaining only a few live needles or leaves.

10. Tree dead.

APPENDIX 4

Example of field tally sheet used in the Hardwood Decline Survey, 1987.

TREE CONDITION ASSESSMENT FORM

Date: ___/___/1987 Surveyors: _____

Site Number: _____ Weather: _____

Location: _____

_____

1 = Broken Stem
2 = Wound
3 = Crack or Seam
4 = Tap holes healed
5 = Tap holes total
6 = Other holes
7 = Fungal structures
8 = Cankers
9 = Insect injury
10 = Other wounds
11 = Swelling
12 = Sprout location
13 = Sprout abundance
14 = Bark sloughing
15 = Other _____
16 = Other _____

Tree No.	Species Code	DBH (cm)	Height (m)	Height to lowest branch (m)	Crown Width (m)		% Dead Branches		% Slight Chlorosis	% Strong Chlorosis	% Early Fall Colour	% Necrosis	% Small Leaves	Crown Class Rating	% Defoliation	Additional Observations															
					N	S	Large	Twigs								1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1																															
2																															
3																															
4																															
5																															
6																															
7																															
8																															
9																															
10																															
11																															
12																															
13																															
14																															
15																															

APPENDIX 5

Mean values for decline index
and decline attributes for each
Hardwood Decline study plot,
for all tree species combined.

APPENDIX 5: Mean values for decline index and decline attributes for each Hardwood Decline study plot, for all tree species combined.

PLOT NUMBER	% DEAD LARGE BRANCHES	% DEAD TWIGS	% SLIGHT CHLOROSIS	% STRONG CHLOROSIS	% EARLY FALL COLOUR	% SMALL LEAVES	% NECROSIS	% INSECT DEFOLIATION	DECLINE INDEX
1	8	10	4	3	2	0.0	0.1	0	10
2	33	16	14	11	17	3.2	3.5	24	29
3	13	16	9	8	3	0.0	0.3	29	17
4	29	15	11	9	11	0.8	1.2	14	25
5	24	13	12	15	22	2.1	4.7	23	23
6	8	10	1	4	5	0.0	0.1	0	10
7	6	8	1	7	9	0.0	0.1	0	9
8	27	18	10	1	2	2.0	0.4	6	24
9	5	8	1	3	6	0.0	0.0	0	7
10	3	3	0	0	0	0.0	3.6	0	3
11	8	10	1	10	4	0.0	1.0	0	11
12	2	2	0	0	0	0.0	2.5	0	2
13	25	8	2	1	1	0.6	0.7	0	17
14	17	13	4	0	2	4.8	1.8	9	16
15	12	11	3	4	4	0.0	0.1	0	12
16	18	21	6	2	9	0.0	0.0	0	21
17	28	16	15	5	18	2.7	2.2	21	25
18	20	12	15	6	15	2.3	2.6	12	20
19	13	14	3	10	8	0.0	0.1	0	16
20	16	17	2	10	14	0.0	0.2	0	19
21	10	12	2	4	36	0.0	1.1	0	12
22	8	11	3	3	0	0.0	0.1	0	10
23	9	12	1	2	10	0.0	0.0	1	11
24	11	14	1	5	8	0.0	0.1	0	14
25	8	11	1	2	1	0.0	0.5	3	10
26	28	18	18	6	17	2.8	1.6	15	26
27	13	16	5	1	4	0.0	1.0	0	15
28	23	13	12	13	5	0.7	1.2	12	22
29	33	17	10	13	9	0.4	1.0	11	29
30	31	17	3	22	1	7.3	1.9	37	30
31	24	8	6	21	2	0.5	0.5	17	21
32	13	14	3	1	1	0.0	1.1	0	14
33	13	14	3	0	6	0.0	0.3	0	14
34	23	10	11	2	1	0.0	0.7	32	18
35	30	6	5	5	3	0.0	0.6	8	19
36	10	11	0	0	0	1.7	0.0	0	11
37	34	13	4	5	1	0.0	0.1	27	25
38	34	9	1	0	0	0.0	0.8	49	22
39	15	16	4	3	1	1.1	0.5	0	17
40	11	13	1	1	2	0.0	2.7	0	12
41	27	18	11	2	2	0.7	2.1	7	24
42	10	4	7	0	5	0.6	0.9	1	8

APPENDIX 5: (continued).

PLOT NUMBER	% DEAD LARGE BRANCHES	% DEAD TWIGS	% SLIGHT CHLOROSIS	% STRONG CHLOROSIS	% EARLY FALL COLOUR	% SMALL LEAVES	% NECROSIS	% INSECT DEFOLIATION	DECLINE INDEX
43	17	9	14	5	2	3.7	3.1	12	16
44	9	11	1	3	25	0.0	0.2	0	11
45	16	11	0	0	0	0.0	0.1	0	14
46	16	8	15	1	3	1.4	1.9	6	14
47	26	11	11	2	4	1.3	2.7	6	20
48	13	13	1	0	0	4.8	1.0	0	14
49	15	7	13	1	4	2.7	0.4	3	13
50	25	18	10	1	3	1.9	2.3	4	23
51	15	8	7	0	6	1.0	0.4	1	13
52	13	15	1	3	10	0.0	0.0	0	15
53	17	8	9	1	2	1.5	1.3	4	14
54	4	4	0	0	0	0.0	2.8	0	4
55	17	10	10	3	2	1.6	2.9	7	15
56	24	17	12	1	4	2.7	0.9	34	23
57	14	5	0	0	0	0.1	0.5	0	9
58	24	13	16	4	3	1.9	2.0	10	21
59	2	2	0	0	0	0.0	1.4	0	2
60	8	11	3	6	6	0.0	0.1	1	11
61	18	20	3	8	31	0.0	0.9	36	21
62	9	11	0	4	46	0.0	1.5	1	11
63	8	10	0	0	0	0.0	2.9	0	9
64	11	13	0	0	0	0.0	4.9	22	12
65	19	21	2	3	51	0.0	0.8	55	21
66	20	23	1	3	44	0.0	2.9	49	22
67	10	12	0	0	0	0.0	3.2	28	11
68	20	9	7	0	4	0.9	0.9	1	15
69	16	7	9	1	6	1.0	0.7	3	12
70	18	7	7	1	6	0.6	1.2	2	14
71	5	5	0	0	0	0.0	4.9	51	5
72	6	6	0	0	0	0.0	0.2	6	6
73	1	1	0	1	0	0.0	0.7	1	2
74	8	11	5	10	6	0.1	1.0	2	12
75	5	5	0	1	3	0.0	2.4	2	5
76	15	17	1	6	24	0.5	2.6	0	17
77	16	17	1	3	18	0.0	0.1	0	17
78	17	8	8	2	10	0.8	1.3	1	14
79	0	0	0	0	0	0.0	0.2	0	0
80	17	17	3	2	46	0.0	0.5	0	18
81	5	5	0	0	0	0.0	4.4	0	5
82	5	5	0	0	0	0.0	3.7	0	5
83	5	5	0	0	0	0.0	2.7	0	5
84	12	14	4	7	7	0.0	1.5	0	15

APPENDIX 5: (continued).

PLOT NUMBER	% DEAD LARGE BRANCHES	% DEAD TWIGS	% SLIGHT CHLOROSIS	% STRONG CHLOROSIS	% EARLY FALL COLOUR	% SMALL LEAVES	% NECROSIS	% INSECT DEFOLIATION	DECLINE INDEX
85	7	9	3	7	10	0.0	0.9	1	10
86	4	4	0	0	0	0.0	1.8	0	4
87	18	7	11	1	4	1.1	3.0	3	14
88	25	14	14	1	5	0.7	0.4	2	21
89	16	18	6	3	3	0.0	0.3	7	19
90	19	20	3	1	7	0.0	0.0	0	20
91	19	21	4	3	6	0.0	0.2	0	21
92	13	15	3	4	2	0.0	0.1	0	15
93	18	20	2	4	0	0.0	0.3	1	19
94	21	8	12	11	4	1.1	1.7	38	18
95	30	13	8	16	2	1.5	0.5	41	26
96	27	18	16	14	28	3.4	1.9	51	28
97	26	18	19	12	22	3.4	1.8	46	27
98	26	18	14	3	9	2.2	1.5	39	25
99	31	18	10	4	7	2.9	1.5	41	27
100	38	22	8	6	42	3.2	3.3	43	33
101	13	14	8	6	1	0.0	0.1	0	16
102	10	11	2	3	6	0.0	0.4	0	11
103	15	17	3	7	7	0.0	0.9	2	18
104	31	16	22	6	15	0.7	3.0	20	27
105	13	13	3	1	0	0.3	0.0	0	14
106	14	14	9	4	1	0.0	0.4	0	16
107	17	18	3	1	1	0.0	0.7	0	18
108	13	11	2	1	0	0.0	0.2	0	12
109	18	15	0	0	0	0.0	6.5	6	16
110	11	10	1	0	0	0.0	0.1	2	11

APPENDIX 6

Summary of additional tree quality observations for sugar maples for each hardwood decline plot, as percent of trees affected, from the 1987 reassessment survey.

APPENDIX 6: Summary of additional tree quality observations for sugar maples for each hardwood decline plot, as percent of trees affected, from the 1987 reassessment survey.

PLOT NUMBER	BROKEN STEM	WOUND	CRACK	OTHER HOLES	FUNGAL STRUCTURES	CANKERS	INSECTS	OTHER WOUNDS	SWELLING	SPROUTING	BARK SLOUGHING
1	0	27	13	0	6	4	99	0	14	38	94
2	0	17	13	0	0	6	97	0	24	21	6
3	0	18	20	3	8	5	97	0	24	9	91
4	0	24	4	0	3	5	99	0	50	66	12
5	0	15	13	0	2	4	98	0	35	15	16
6	6	40	19	4	3	9	51	3	16	9	54
7	0	46	17	4	5	2	45	0	44	7	57
8	0	29	6	0	0	0	43	0	31	11	14
9	0	12	1	1	7	1	40	0	14	12	36
10	0	1	1	50	1	0	100	0	25	49	1
11	0	38	26	3	5	5	17	0	2	2	83
12	0	5	1	21	0	0	100	0	8	37	0
13	2	13	6	0	2	8	92	1	4	0	7
14	0	24	0	0	0	2	62	0	19	8	36
15	2	15	14	6	2	13	97	1	34	5	87
16	2	13	2	0	0	0	95	0	11	21	90
17	0	24	7	0	4	10	89	0	22	33	8
18	0	30	19	0	0	1	90	0	22	45	3
19	0	13	18	1	4	0	71	0	19	25	76
20	0	18	7	0	4	2	96	0	15	15	87
21	0	19	10	1	5	1	95	0	13	15	89
22	0	8	2	2	3	0	98	0	8	15	76
23	0	22	12	1	1	0	97	0	9	20	68
24	0	26	18	0	2	3	98	0	16	15	76
25	0	19	11	0	6	2	98	0	6	31	69
26	0	27	3	3	2	0	84	0	29	71	5
27	0	24	13	0	0	3	100	0	19	16	85
28	0	19	0	0	0	4	92	1	38	45	8
29	0	17	5	0	0	2	83	0	44	38	20
30	0	40	16	0	7	7	91	1	31	5	18
31	0	33	13	7	2	10	89	0	40	15	23
32	0	23	32	3	2	6	97	2	31	21	87
33	2	29	16	11	0	22	84	0	22	24	76
34	0	20	5	2	7	0	91	0	9	5	25
35	2	19	8	0	5	2	77	0	16	5	6
36	0	23	44	0	3	1	99	0	0	0	0
37	0	15	18	0	0	3	92	0	11	10	31
38	0	7	0	0	1	3	94	0	8	0	0
39	4	14	19	7	5	7	91	0	41	10	79

APPENDIX 6 (continued):

PLOT NUMBER	BROKEN STEM	WOUND	CRACK	OTHER HOLES	FUNGAL STRUCTURES	CANKERS	INSECTS	OTHER WOUNDS	SWELLING	SPROUTING	BARK SLOUGHING
40	0	15	37	2	4	17	98	0	30	13	59
41	0	31	3	0	0	5	55	0	20	20	22
42	0	22	1	0	1	0	9	0	20	3	32
43	0	25	7	0	0	1	90	0	31	27	27
44	0	14	1	4	0	0	100	0	12	14	90
45	2	15	2	5	1	10	46	5	0	4	27
46	0	15	0	0	0	2	42	0	20	7	16
47	0	7	1	0	3	7	40	4	11	7	33
48	1	26	3	0	1	4	78	17	0	14	99
49	0	13	0	0	1	0	33	0	16	4	43
50	4	35	4	0	4	2	54	2	33	7	26
51	0	27	2	0	2	2	14	0	17	5	22
52	0	14	10	0	0	2	92	0	16	16	80
53	0	20	0	0	0	1	28	1	9	6	29
54	0	4	5	32	4	0	100	0	32	43	9
55	0	17	0	0	0	1	60	0	14	22	42
56	0	11	2	0	1	5	91	0	24	9	29
57	0	2	0	1	1	0	46	2	1	0	2
58	0	13	3	0	0	0	70	0	26	22	35
59	0	9	0	19	0	1	100	0	5	56	0
60	0	27	14	0	9	5	98	0	10	14	69
61	0	17	19	3	10	3	92	0	23	15	92
62	0	24	17	0	3	3	97	0	14	11	86
63	0	2	2	30	0	0	100	0	67	70	3
64	1	4	20	52	10	1	100	0	51	32	1
65	0	13	25	0	2	7	95	0	23	11	87
66	0	32	14	0	2	14	96	0	25	12	96
67	0	0	8	41	5	0	100	0	37	20	5
68	0	14	3	0	0	1	11	0	12	4	51
69	0	42	2	0	0	3	27	0	13	15	5
70	0	17	0	1	0	1	16	0	16	5	25
71	0	0	1	27	6	1	100	0	0	35	14
72	0	0	0	45	0	1	100	0	23	61	1
73	0	0	5	28	2	3	100	0	48	32	3
74	3	23	4	4	3	4	61	9	16	34	57
75	2	13	2	30	3	0	100	0	10	42	0
76	0	18	0	3	0	3	93	0	10	27	85
77	2	16	9	0	0	0	89	0	12	32	53
78	0	34	1	0	2	0	4	0	14	11	24

APPENDIX 6 (continued):

PLOT NUMBER	BROKEN STEM	WOUND	CRACK	OTHER HOLES	FUNGAL STRUCTURES	CANKERS	INSECTS	OTHER WOUNDS	SWELLING	SPROUTING	BARK SLOUGHING
79	1	15	3	40	1	1	100	0	28	32	1
80	0	31	0	0	2	0	49	0	16	11	49
81	0	0	0	22	4	0	100	0	20	14	10
82	0	3	0	25	0	16	79	0	24	24	9
83	0	12	1	38	9	0	100	0	41	20	5
84	0	28	12	1	4	1	96	0	11	27	73
85	0	22	2	2	2	1	99	0	15	34	74
86	0	10	0	18	5	0	100	0	31	26	2
87	0	15	5	0	0	0	18	0	14	14	19
88	0	36	0	0	0	0	6	0	11	2	6
89	1	19	28	1	4	1	99	0	23	21	99
90	0	24	46	4	10	4	97	0	23	13	94
91	9	19	35	0	20	14	96	0	25	24	92
92	0	22	36	0	14	9	99	0	23	7	91
93	0	19	3	0	0	0	96	0	13	19	91
94	0	42	6	0	0	3	100	1	55	28	8
95	0	34	6	0	2	5	96	0	48	33	36
96	0	21	15	2	2	12	95	1	22	23	10
97	1	20	9	0	0	8	96	0	26	13	23
98	0	34	9	0	1	2	90	1	25	15	14
99	0	30	8	0	1	13	95	0	27	24	16
100	0	24	5	0	0	3	97	0	40	21	33
101	0	21	9	0	5	2	99	0	15	10	99
102	0	21	6	2	1	0	99	0	9	32	94
103	1	21	7	1	3	4	96	0	18	19	92
104	0	25	7	0	0	3	96	0	25	51	4
105	0	37	6	0	6	3	100	0	0	0	0
106	0	24	15	3	3	7	92	0	36	8	93
107	0	20	23	4	2	1	93	0	16	19	81
108	2	7	27	8	9	15	99	0	19	8	93
109	0	9	13	7	9	20	93	0	42	11	91
110	0	14	6	6	11	36	79	0	18	0	96

APPENDIX 7

Maps of insect defoliation
and Gypsy Moth egg mass sightings
in Ontario, 1986-1987.

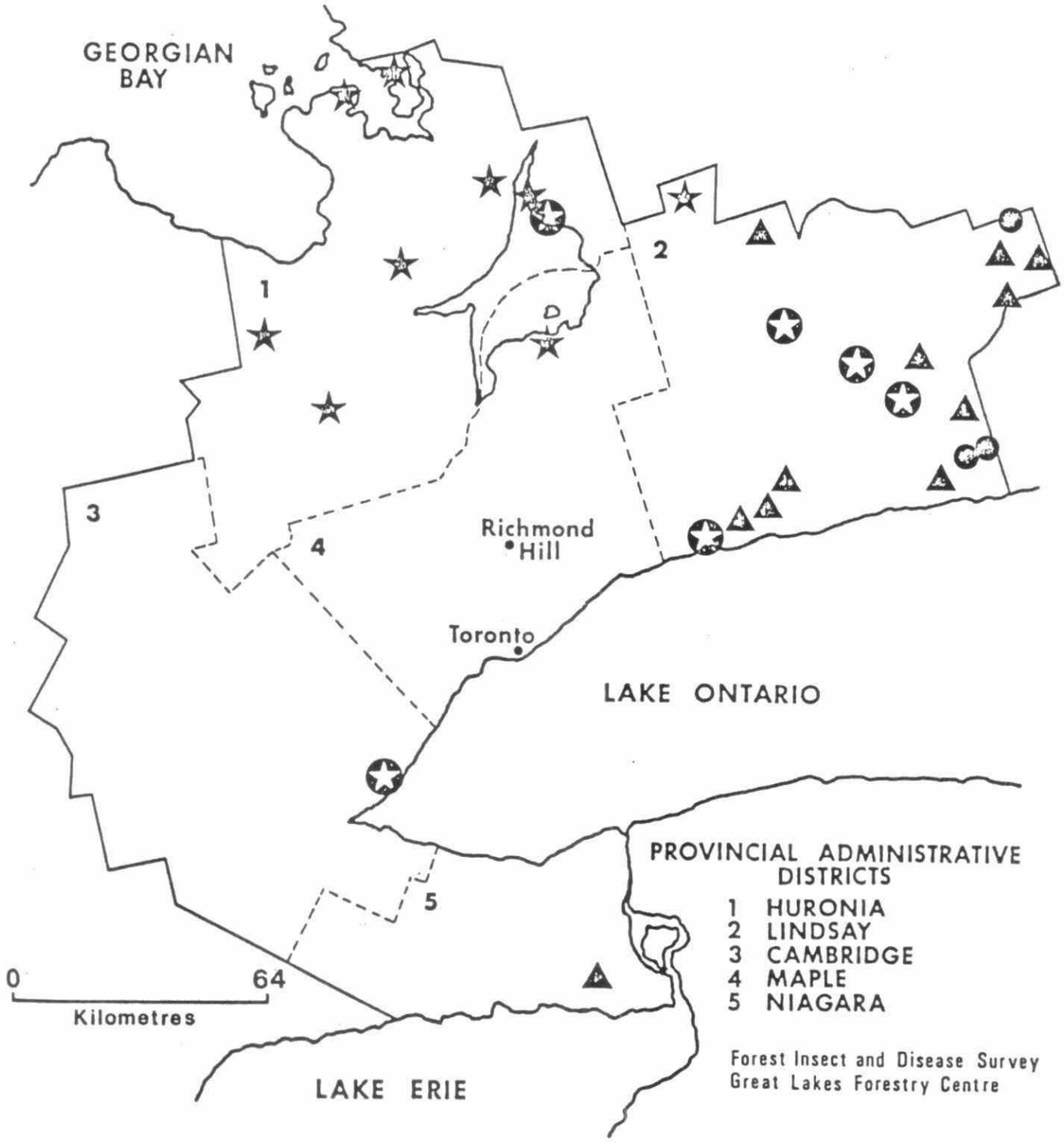
SOUTHWESTERN REGION

Gypsy Moth
(*Lymantria dispar* [L.])

Confirmed locations of larvae or egg masses, 1985-1987 ..... ●

Forest Insect and Disease Survey
Great Lakes Forestry Centre

CENTRAL REGION



Gypsy Moth, *Lymantria dispar* (L.) 1986

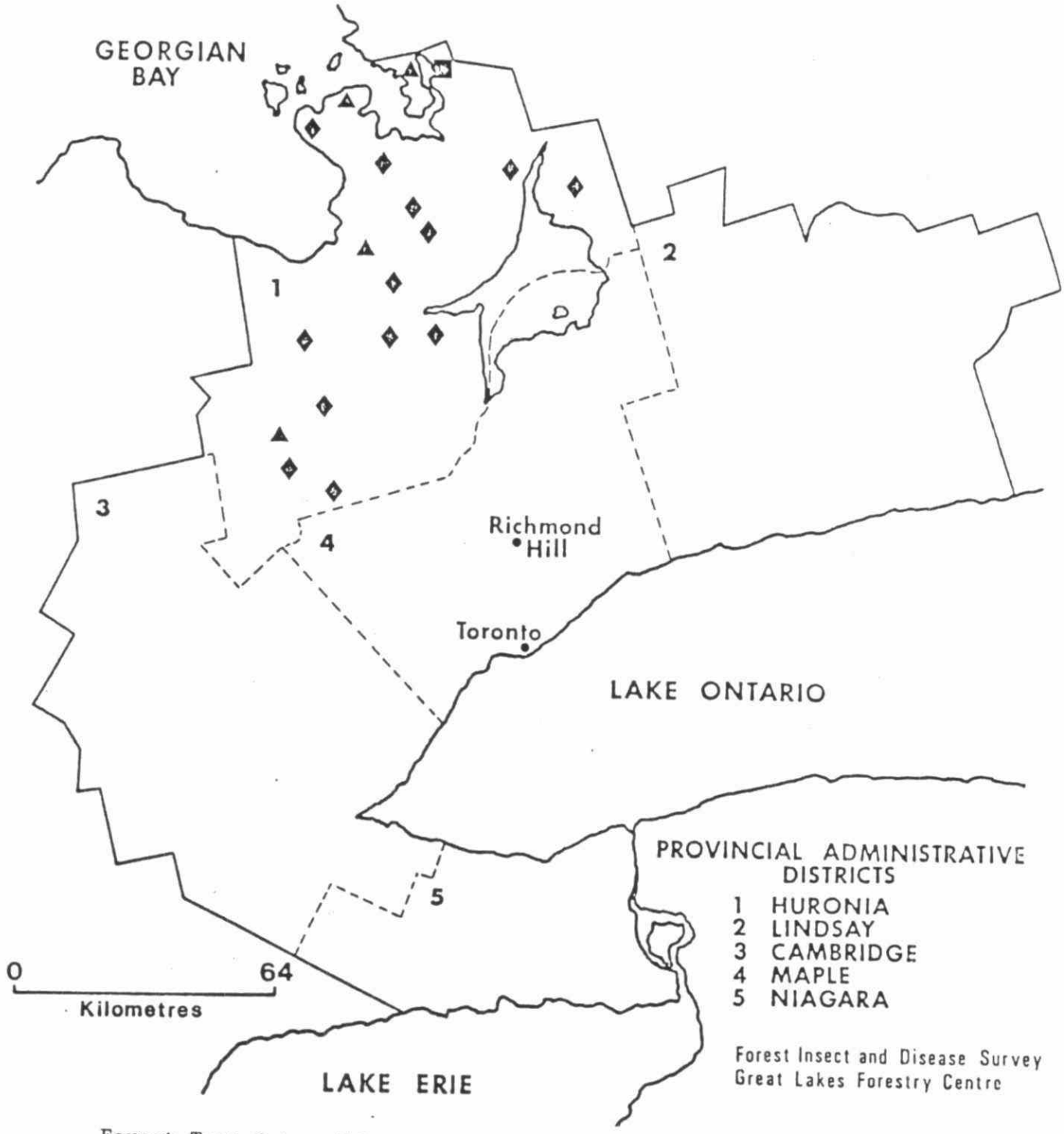
Moderate-to-severe defoliation.....

Trace larval populations.....

Pheromone trap locations:
Moths captured.....

Moths and trace larvae.....

CENTRAL REGION



Forest Tent Caterpillar, *Malacosoma disstria* Hbn. 1986

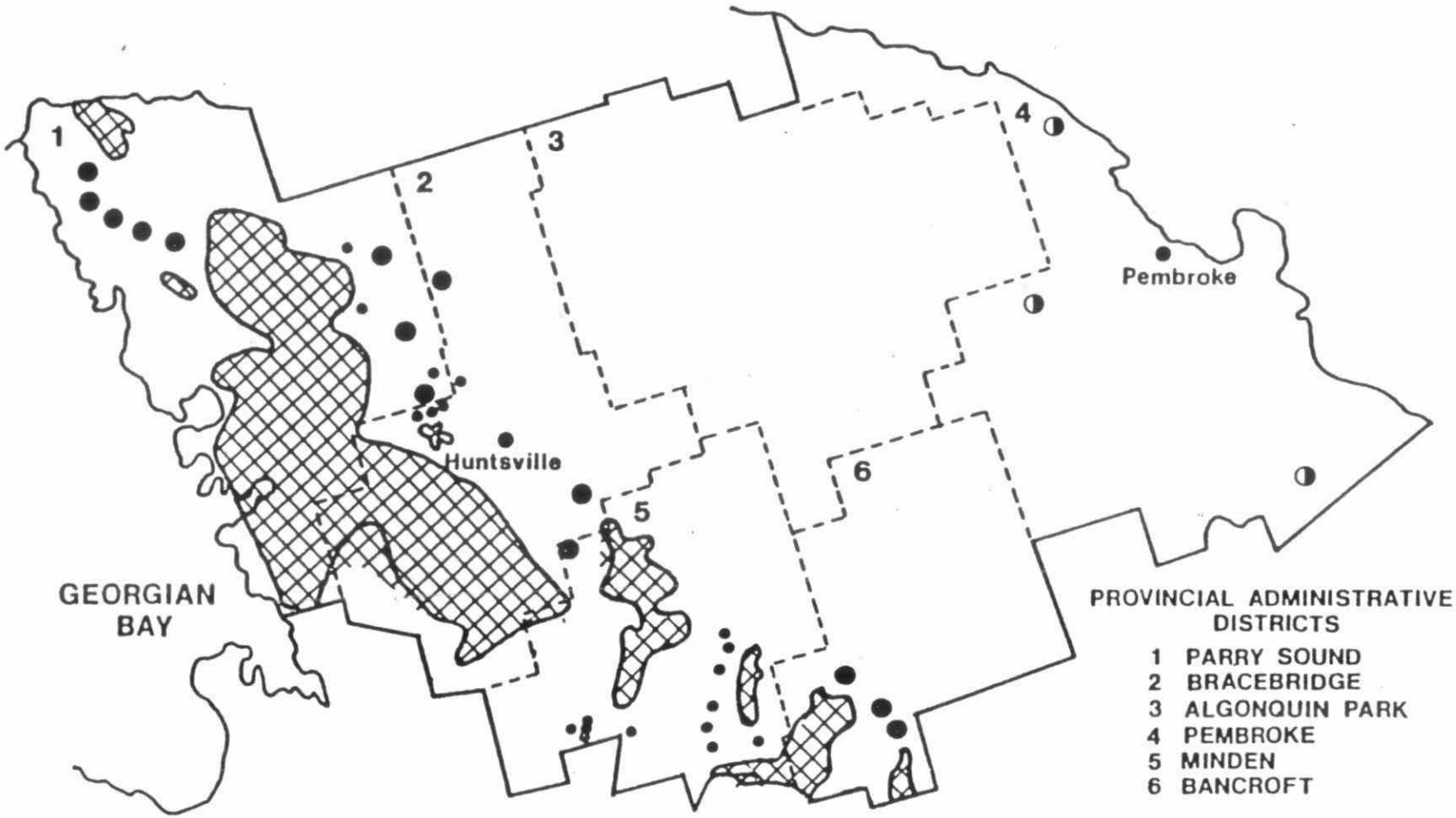
Infestation forecast for 1987

Moderate..... ■

Light..... ▲

Nil..... ◆

ALGONQUIN REGION



0 64

Kilometres

Forest Insect and Disease Survey
Great Lakes Forestry Centre

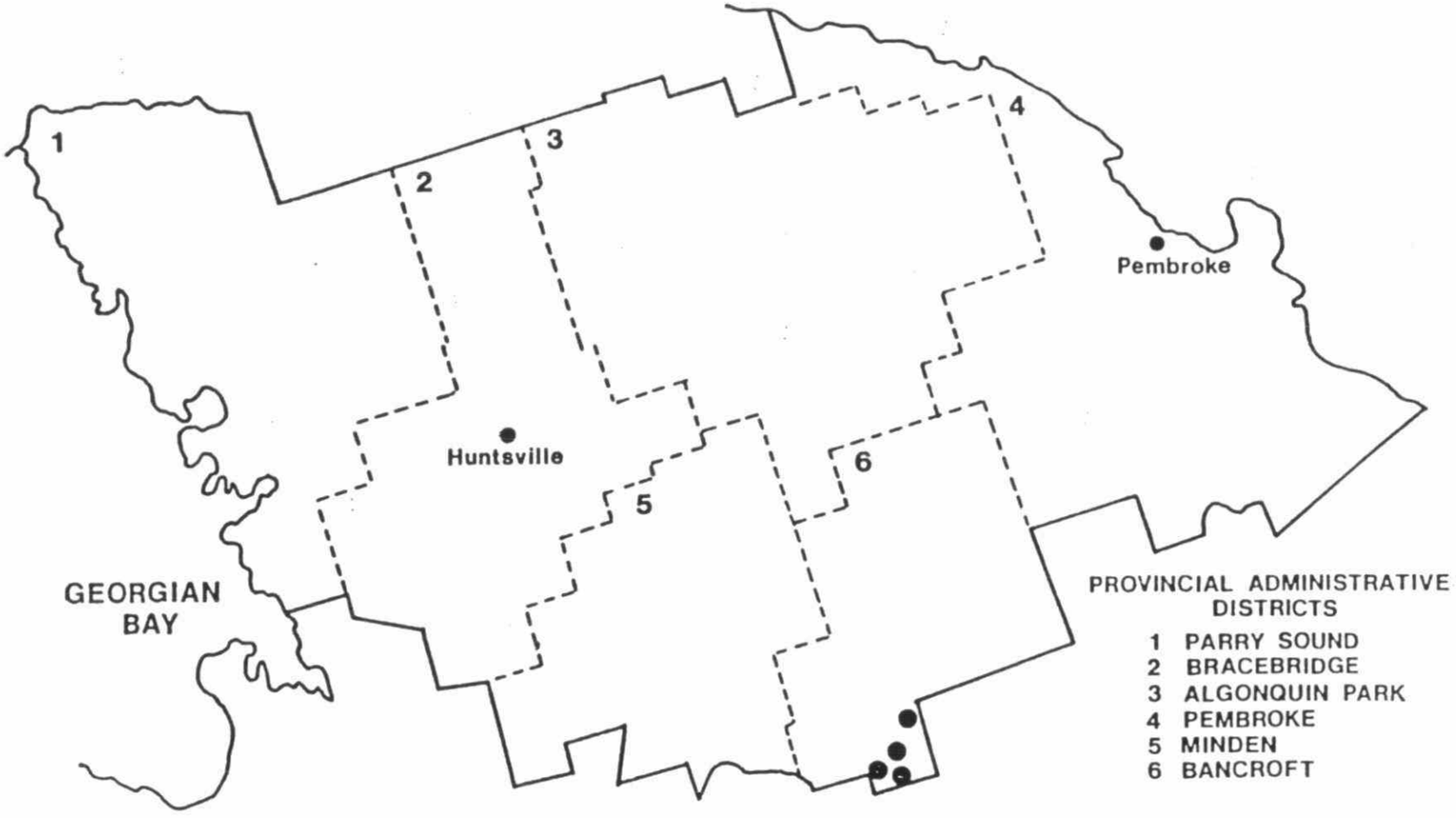
Forest Tent Caterpillar
(*Malacosoma disstria* Hbn.)

Areas within which defoliation occurred in 1987

Trace .....◑

Moderate-to-severe .....⊠ or ●

ALGONQUIN REGION



0 64

Kilometres

Forest Insect and Disease Survey
Great Lakes Forestry Centre

Gypsy Moth (*Lymantria dispar* [L.])

Areas within which moderate-to-severe defoliation occurred in 1987 ..... ●

APPENDIX 8

K-Means cluster analysis results for the hardwood decline plots, for all tree species combined, using seven decline attributes.

APPENDIX 8

K-Means cluster analysis results for the hardwood decline plots, for all tree species combined, using seven decline attributes. The output shows summary statistics for the six groups formed and the plot membership of each cluster group.

SUMMARY STATISTICS FOR 6 CLUSTERS

VARIABLE	BETWEEN SS	DF	WITHIN SS	DF	F-RATIO	PROB
DEADLARG	6327.643	5	1716.314	104	76.685	0.000
DEADTWIG	1144.161	5	1663.157	104	14.309	0.000
SLIGHT	1941.818	5	1171.249	104	34.484	0.000
STRONG	962.799	5	1240.823	104	16.139	0.000
EARLYFAL	11187.075	5	2058.206	104	113.055	0.000
SMLEAVES	52.695	5	127.900	104	8.570	0.000
NECROSIS	22.558	5	166.098	104	2.825	0.020

CLUSTER NUMBER: 1

MEMBERS

CASE	DISTANCE
1	1.51
6	1.82
7	3.21
9	1.83
10	2.89
11	3.36
12	3.22
15	2.45
22	1.63
23	3.49
25	1.30
36	2.12
40	2.52
42	3.03
48	3.56
54	2.12
57	2.98
59	3.16
60	2.68
63	1.51
64	2.86
67	2.19
71	2.14
72	1.48
73	3.48
74	3.82
75	1.63
79	4.15
81	2.17
82	2.10
83	2.03
85	3.67
86	2.22
102	2.18
108	2.64
110	2.11

STATISTICS

VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
DEADLARG	0.15	7.22	13.65	3.45
DEADTWIG	0.15	7.84	12.90	3.73
SLIGHT	0.00	1.11	7.05	1.60
STRONG	0.00	1.89	10.15	2.80
EARLYFAL	0.00	2.23	10.10	3.11
SMLEAVES	0.00	0.20	4.80	0.83
NECROSIS	0.00	1.43	4.90	1.52

APPENDIX 8 (continued).

CLUSTER NUMBER: 2

MEMBERS		STATISTICS				
CASE	DISTANCE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
21	2.44	DEADLARG	9.23	14.79	20.20	4.26
44	5.63	DEADTWIG	11.15	16.53	22.60	4.31
61	3.62	SLIGHT	0.15	1.58	3.35	0.90
62	4.19	STRONG	2.10	4.23	8.15	1.88
65	5.41	EARLYFAL	23.65	37.70	50.60	9.60
66	3.92	SMLEAVES	0.00	0.07	0.50	0.16
76	5.38	NECROSIS	0.23	1.32	2.85	0.90
80	3.37					

CLUSTER NUMBER: 3

MEMBERS		STATISTICS				
CASE	DISTANCE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
3	3.12	DEADLARG	11.38	17.44	26.85	4.31
8	4.29	DEADTWIG	6.70	13.56	21.35	4.20
13	3.98	SLIGHT	0.05	6.65	16.20	4.34
14	2.25	STRONG	0.00	2.59	10.15	2.54
16	3.46	EARLYFAL	0.00	4.20	17.87	3.68
19	3.96	SMLEAVES	0.00	0.75	4.75	1.07
20	5.17	NECROSIS	0.00	1.02	6.47	1.20
24	3.59					
27	2.13					
32	2.61					
33	2.56					
34	3.54					
39	1.86					
41	4.35					
43	3.76					
45	3.29					
46	3.94					
47	3.61					
49	3.58					
50	3.59					
51	2.55					
52	3.48					
53	2.68					
55	2.34					
56	3.77					
58	4.42					
68	2.35					
69	3.02					
70	2.76					
77	5.77					
78	3.08					
84	3.04					
87	3.08					
88	3.90					
89	1.99					
90	3.11					
91	3.16					
92	2.58					
93	3.36					
101	2.46					
103	2.75					
105	2.67					
106	2.08					
107	2.47					
109	3.68					

APPENDIX 8 (continued).

CLUSTER NUMBER: 4

MEMBERS		STATISTICS				
CASE	DISTANCE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
100	0.00	DEADLARG	38.39	38.39	38.39	0.00
		DEADTWIG	21.90	21.90	21.90	0.00
		SLIGHT	8.50	8.50	8.50	0.00
		STRONG	6.41	6.41	6.41	0.00
		EARLYFAL	42.33	42.33	42.33	0.00
		SMLEAVES	3.19	3.19	3.19	0.00
		NECROSIS	3.33	3.33	3.33	0.00

CLUSTER NUMBER: 5

MEMBERS		STATISTICS				
CASE	DISTANCE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
2	2.78	DEADLARG	20.40	27.00	33.21	3.51
5	3.65	DEADTWIG	12.15	16.03	18.30	2.02
17	1.45	SLIGHT	12.10	16.16	21.90	2.84
18	3.32	STRONG	2.65	8.67	14.75	4.11
26	1.55	EARLYFAL	9.40	18.34	28.35	5.08
96	4.36	SMLEAVES	0.70	2.52	3.40	0.80
97	2.36	NECROSIS	1.49	2.51	4.65	0.99
98	4.25					
104	3.04					

CLUSTER NUMBER: 6

MEMBERS		STATISTICS				
CASE	DISTANCE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
4	3.14	DEADLARG	20.80	29.00	33.90	4.22
28	3.05	DEADTWIG	5.60	12.46	18.35	4.10
29	3.23	SLIGHT	0.70	7.33	12.35	3.72
30	5.33	STRONG	0.00	10.83	21.50	6.66
31	4.87	EARLYFAL	0.35	4.04	10.80	3.43
35	3.60	SMLEAVES	0.00	1.37	7.30	2.04
37	3.36	NECROSIS	0.05	0.98	1.90	0.55
38	5.51					
94	4.01					
95	2.28					
99	3.72					

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